

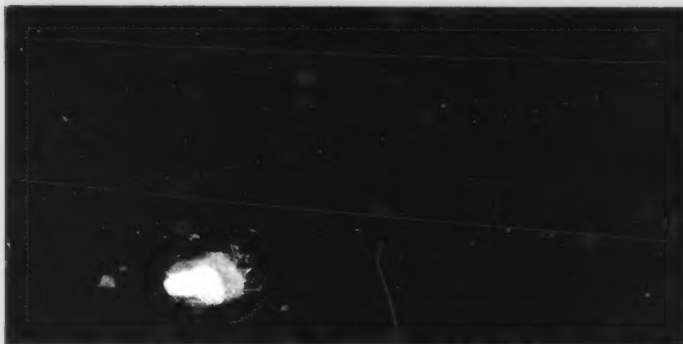


Energy, Mines and
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Minister

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Ministre



Canada

SCALD PROTECTION
IN
SOLAR DOMESTIC HOT WATER SYSTEMS
RENEWABLE ENERGY BRANCH

PREPARED FOR:

Renewable Energy Branch
Energy, Mines and Resources Canada
Ottawa, Canada
DSS Contract File No.: 23216-6-6080/01-SZ
October, 1987

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Citation

Sibbitt, B.E.,

Ontario Research Foundation. Scald Protection in Solar Domestic Hot Water Systems. Report of Contract File # 23216-6-6080/01-SZ.

Renewable Energy Branch; Energy, Mines and Resources Canada,
Ottawa, Ontario. 1987. (95 pp.)

Copies of this report may be obtained through:

Renewable Energy Branch
Energy, Mines and Resources Canada
580 Booth Street
Ottawa, Ontario
K1A 0E4
(613) 995-9447

c Minister of Supply and Services Canada

Catalogue No.:

ISBN No.:

Funding for this report was provided by the Panel of Energy
Research and Development, Office of Energy Research and Development,
Energy, Mines and Resources Canada

Acknowledgements

The work described in this report was carried out by the Energy Systems Centre, Engineering Division, Ontario Research Foundation under contract to the Solar Energy Development Program of the Renewable Energy Branch, Energy Mines and Resources Canada. Their financial support is gratefully acknowledged. The Materials Corrosion Section, Materials Division, ORF examined the valves after the testing and suggested an accelerated aging procedure for them. The author would also like to acknowledge the assistance of all those who contributed to the test program and this report.

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Preface

This report is a summary of several activities intended to gather together existing information and provide new information related to scald protection in solar domestic hot water systems.

The work carried out under this contract included:

- (1) A search for and review of standards for tempering valves.
- (2) Transient testing of tempering valves that cover a wide range of prices.
- (3) Testing of auxiliary hot water tanks as a means of limiting SDHW system outlet temperatures.
- (4) Definition of an accelerated aging procedure for tempering valves.
- (5) Review of the Routine Overtemperature Test in CSA F379 in light of the results of the other parts of this study.

The audience for the report is expected to include three groups:

- (1) System manufacturers who it is hoped will make use of the test results in their selection of components and system configurations in the design of SDHW systems.
- (2) Standards writers primarily the Technical Committee for CSA F379 for information on component performance and related standards.
- (3) Solar program managers and administrators (in government) as an input in steering R & D and product development efforts.

It must be stated that the tests performed under this contract were intended to be exploratory in nature. While the measurements were made carefully, the valves purchased for testing were very new, and most results presented are based on a single test per valve. Similarly, the auxiliary tank as a buffer test employed only one tank and a single test for each condition. For both tank and valve testing only a limited number of test conditions were examined.

Abstract

The outlet water temperature produced by a solar domestic hot water (SDHW) system can vary over a wide range, depending on weather conditions and the size of load imposed. Water can be heated to temperatures that can cause pain and scalding if contact with human tissue is allowed to occur. It is therefore important to provide reliable means to limit the temperature of water leaving such systems.

The objectives of this study were:

- (1) to experimentally evaluate the performance of tempering valves and auxiliary water tanks for their abilities to prevent scalding water from reaching the user;

- (2) to develop an accelerated aging procedure for tempering valves;
- (3) to find and review standards related to tempering valves and to make recommendations on the sections of CSA Standard F379.1 pertaining to scald protection, based on information gathered in the study.

Transient tests were performed on six pairs of new tempering valves, one used valve and an auxiliary electric water tank. In each case the outlet temperature was monitored for a range of operating conditions.

A wide variation exists in the performance of the valves in terms of the outlet temperature overshoot and time required to return to the setpoint. In general, there was less chance of scalding at low flow rates with low inlet water temperature and low setpoints. The preheat tank reduced the outlet temperature for a period of time in each test conducted. Some applicable standards documents were found to be too stringent in their performance requirements.

The major significance of this project lies in the reporting of previously unavailable data on components that are critical to the safety of SDHW system users. Since the approach taken to limiting outlet temperatures affects both the energy output and system cost, it could have a significant impact on the economics and safety of SDHW systems.



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EXECUTIVE SUMMARY

The outlet water temperature produced by a solar domestic hot water (SDHW) system can vary over a wide range, depending on weather conditions and the size of load imposed. Under some circumstances water will be heated to temperatures that can cause pain and scalding if contact with human tissue is allowed to occur. It is therefore important to provide reliable means to limit the temperature of water leaving such systems.

Current techniques involve the use of a tempering valve, a controller which stops collector pump operation when a preset tank temperature is reached or a combination of both methods. Both safety and economic factors enter into the choice of a high-limit temperature control strategy. An earlier study^[4] presented the test results for three low cost valves but the accuracy of the transient data was uncertain and the report recommendations left the onus for scald prevention on the user.

In the work reported herein, tests were performed on six pairs of new tempering valves and one used more expensive valve, using a test apparatus specifically designed for this project. A test consisted of operating a valve for one minute with fixed hot and cold water supply temperatures and a preset outlet flow rate, while measuring both supply temperatures and the outlet temperature with fast response thermocouples. Each valve was tested with hot supply water temperatures of 49, 71 and 93°C and flow rates of 4 and 14 l/min (at each temperature). Each of these tests was performed for two setpoints (49 and 60°C) on those valves. One valve of each pair was tested from a hot starting condition, while the other was tested from a cold start. The outlet temperature was measured and recorded at 0.2 second intervals.

Significant variation was found to exist in the performance of the valves tested, in terms of temperature overshoot and time required to return to setpoint temperature. In general, the valves performed better (less chance of scalding because of less overshoot and faster response) at the low flow rate.

Even the best performing valve tested, the MCC Powers Hydroguard 420, (\$459) produced high water temperatures (potentially scalding) for short periods, under some conditions. The next to best performing valve, the Sparco Aquamix AM 100, was significantly less expensive (\$64) and its performance was somewhat inferior.

The less than desirable performance of the tempering valves tested suggests that in order to prevent humans from scalding temperatures they should be used in conjunction with some other means of limiting the outlet temperature. A small storage volume located downstream of the valve might be sufficient for this purpose. The 49°C setpoint temperature generally resulted in significantly safer valve outlet temperatures than the 60°C setpoint. A supply temperature of 49°C (120°F) should be more than adequate for all sink/shower loads but higher temperature water for the dishwasher and clothes washer may be desirable and obtained by a separate untempered supply line to these appliances.

Tests were also performed on an electrically heated auxiliary tank (60°C setpoint) with 71 and 93°C hot water supply temperatures and flow rates of 4 and 14 L/min (at each temperature).

The two element auxiliary tank can reduce the likelihood of scalding hot water reaching the user, but its 60°C setpoint was exceeded in 1.5 to 9.0 seconds, depending on inlet water temperature and flow rate. The tempering capability of an auxiliary tank cannot always be relied upon since the solar system may, at times, fill the tank with dangerously hot water.

The situation is similar for electrically heated tanks with only the top element operational except that:

- (1) Less hot water will be available to the load at times of low or moderate solar contribution (about 30 litres of hot water at the setpoint). The supply temperature therefore may drop well below setpoint after this volume of hot water has been drawn.
- (2) Significantly more time elapses (8 to 25 seconds) before the setpoint temperature is exceeded when the tank is supplied with water above the setpoint.

It may be possible to define optimum periods for an operating strategy that uses both elements of an electric auxiliary in the lower solar fraction months, (when the probability of encountering higher solar heated water temperatures is low) and uses only the top element in the highest solar fraction months (so that the probability of having insufficient hot water is reduced).

Three problems which may ultimately lead to failure or malfunctioning of a tempering valve are: (1) scaling, (2) galvanic corrosion, and (3) impingement corrosion. The valves purchased for test were disassembled and inspected for evidence of those problems and an accelerated aging procedure was devised. It involves operating the subject valve at typical operating temperatures and a flow rate of 10 l/min over a cycle of 15 minutes of operation and 45 minutes of no flow, repeated for approximately 23 days.

In the search for standards related to tempering valves five documents were obtained and reviewed including: two ASTM Consumer Safety Specifications; two ANSI/ASSE (American Society of Sanitary Engineering) Mixing Valve Performance Standards and the CSA Standard CAN3-B125-M85 Plumbing Fittings.

The ASTM Consumer Safety Specifications and the corresponding performance requirements in the ANSI/ASSE Standards were too stringent relative to the standard practice of setting conventional hot water tanks at about 60°C. Minor changes to CAN3-B125-M85 primarily with respect to testing temperatures should make it suitable for tempering valves used in the SDHW systems.

The sections of CSA Standard F379.1 dealing with routine overtemperature and scald protection have been significantly improved by the Technical Committee within the last year but a few changes are suggested. These include: the maximum allowable temperature to the user should be reduced to 60°C (from the current 63°C); and a faster response temperature sensor should be specified to measure the draw water temperature.

The most important conclusions include:

- (1) the next to best performing tempering valve tested combined reasonable new performance with moderate cost;
- (2) tempering valves are best used in conjunction with some other means of limiting the water temperature since all valves tested produced dangerous outlet water temperatures under some conditions;
- (3) auxiliary tanks will generally reduce the temperature of very hot water entering them but this buffering capacity may be used up when large amounts of very hot water are produced by the SDHW system;
- (4) the current draft sections of CSA F379.1-M1985 addressing routine overtemperature and scald protection are fundamentally sound and require only improvements to specific details;
- (5) with a limited number of changes CAN 3-B125-M85 would be reasonably well suited to testing tempering valves for the SDHW system application.

It is recommended that the performance of "aged" tempering valves be investigated since their operation after several years of use is just as important as when new. It is also suggested that SDHW system simulation be used to help define a preferred design mix for tempering valves and other means of high limit temperature control. Some promising hardware should also be evaluated. Efforts by manufacturers should be directed to production of better tempering valves with good control of outlet water temperature.

The prime importance of the work described here is that some tempering valve and auxiliary tank and performance data is now available. Its value is limited by the small number of test conditions and most importantly by the fact that the valves tested were new. However, the data collected may form the basis for further work (focussed by what has been done) and can be used, until better information becomes available, to make decisions regarding standards, system design and product development.

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RÉSUMÉ

La température de l'eau fournie par un chauffe-eau solaire résidentiel peut varier sensiblement selon les conditions atmosphériques et la taille de la charge imposée. Dans certains cas, l'eau atteint une température insupportable et peut ébouillanter le tissu cellulaire. Il est donc important de limiter la température de l'eau qui sort du chauffe-eau.

On peut soit utiliser une soupape de mélange soit un dispositif de contrôle qui arrête la pompe d'insolateur quand le réservoir atteint la température prédéterminée ou encore une combinaison des deux méthodes. Les critères de sécurité et les facteurs économiques entrent dans le choix de la méthode de contrôle de la température maximale. Une étude antérieure⁴ a présenté les résultats des tests concernant trois soupapes peu coûteuses, mais l'exactitude des données transitoires était douteuse et les recommandations du rapport laissent à l'utilisateur le soin de se protéger contre les températures extrêmes.

Dans l'étude décrite ici, six paires de soupapes neuves et une soupape usagée plus chère dotée d'un dispositif conçu spécialement pour le projet ont été testées. Pendant une minute, on a fait circuler de l'eau froide et de l'eau chaude aux températures fixées et au débit prédéterminé pendant que l'on mesurait la température d'arrivée et la température de sortie de l'eau avec des thermocouples très sensibles. Ensuite, chaque soupape a été testée avec de l'eau à 49, 71 et 93°C à un débit de 4 et 14 l/min (à chaque température). Chaque test a été effectué à deux températures (49 et 60°C) avec les soupapes. On a ensuite testé une soupape de chaque paire à chaud et l'autre à froid en mesurant et en enregistrant la température d'arrivée toutes les 0,2 seconde. Ces essais ont démontré une forte fluctuation de la performance des soupapes en ce qui concerne le dépassement de la température et le temps nécessaire pour revenir à la température prédéterminée. En général, la performance des soupapes a été meilleure quand le débit de l'eau était normal (moins de risques d'ébouillantage à cause du dépassement moins important et de la réaction plus rapide).

La meilleure soupape, la MCC Powers Hydroguard 420 (459 \$), a donnée de l'eau très chaude (proche du point d'ébullition) pendant de courtes périodes, dans certaines conditions. La soupape qui vient ensuite, la Sparco Aquamix AM 100, était nettement moins chère (64 \$) et sa performance légèrement inférieure.

Il semblerait possible de réduire les risques d'ébouillantage posés par les soupapes en les dotant d'un dispositif de contrôle de la température de sortie. Pour ce faire, il suffirait de placer un petit contenant en aval de la soupape. La température prédéterminée de 49°C a généralement créé des températures de sortie nettement plus sûres que la température de 60°C. Une température d'arrivée de 49°C (120°F) semble largement suffisante pour les lavabos et les douches alors qu'une température plus élevée semble préférable pour les lave-vaisselle et les machines à laver alimentées par une conduite séparée.

On a aussi fait des tests sur un réservoir auxiliaire électrique (température prédéterminée de 60°C) avec des températures d'arrivée de 71 et 93°C et un débit de 4 et 14 l/m (à chaque température).

Le réservoir auxiliaire à deux éléments peut réduire les risques d'ébouillantage, mais sa température prédéterminée de 60°C a été dépassée en 1,5 à 9 secondes, selon la température d'arrivée et le débit de l'eau. On ne peut pas toujours se fier au pouvoir de mélange du réservoir auxiliaire parce que le chauffe-eau le remplit parfois d'eau à une température dangereusement élevée.

Il en est de même des réservoirs électriques qui n'ont que l'élément supérieur, à quelques exceptions près:

- 1) Moins d'eau chaude est disponible à la charge quand l'apport solaire est faible ou modéré (environ 30 litres d'eau chaude à la température prédéterminée). La température d'arrivée peut donc être nettement inférieure à la température prédéterminée quand ce volume d'eau est épuisé.
- 2) Il faut beaucoup plus de temps (de 8 à 25 secondes) pour dépasser la température prédéterminée quand la température de l'eau arrivant au réservoir est supérieure à la température prédéterminée.

Il peut être possible de définir les périodes optimales d'une méthode d'exploitation qui intégrerait les deux éléments d'un réservoir auxiliaire électrique pendant les mois où l'énergie solaire est la plus faible (quand il est moins probable que le soleil porte l'eau à des températures très élevées) et n'utiliserait que l'élément supérieur pendant les mois où l'énergie solaire est la plus élevée (afin d'éviter le manque d'eau chaude).

La panne et le mauvais fonctionnement d'une soupape sont dus: 1) à la formation de tartre, 2) à la corrosion galvanique, 3) à la corrosion de contact. On a démonté et inspecté les soupapes achetées pour les tests afin de déceler les signes de ces conditions et on a conçu une méthode de datation accélérée qui consiste à soumettre la soupape à des températures types et à un débit de 10 l/m pendant 15 minutes suivies de 45 minutes d'arrêt pendant environ 23 jours.

Pour établir les normes des soupapes, cinq documents ont été étudiés, dont deux documents spécifications américaines (ASTM Consumer Safety Specifications), deux documents décrivant les normes de ANSI/ASSE (American Society of Sanitary Engineering) Mixing Valve Performance Standards et la norme ACNOR CAN3-B125-M85 Plumbing Fittings.

Les normes ASTM et les règles d'exécution correspondantes des normes ANSI/ASSE sont trop rigoureuses en ce qui concerne la pratique normale de fixer à 60°C la température des réservoirs d'eau chaude. Les petits changements à la norme CAN3-B125-M85 concernant les températures des tests devraient convenir aux soupapes utilisées dans les chauffe-eau solaires résidentiels.

Les parties de la norme ACNOR F379.1 visant le dépassement de la température et la protection contre l'ébouillantage ont été sensiblement améliorées par le Comité technique en 1986, mais quelques changements sont proposés. On propose notamment de porter de 63°C à 60°C la température maximale recommandée à l'utilisateur et d'adopter une soude de mesure plus sensible pour mesurer la température de l'eau soutirée.

Voici les principales conclusions de l'étude:

- 1) la soupape qui se classe après la meilleure a une performance satisfaisante et un prix modéré;
- 2) il est préférable que la soupape soit dotée d'un dispositif de contrôle de la température de l'eau parce que toutes les soupapes testées ont produit de l'eau beaucoup trop chaude dans certaines conditions;
- 3) les réservoirs auxiliaires réduisent généralement la température de l'eau qui y parvient, mais le pouvoir tampon peut disparaître quand le chauffe-eau produit une grande quantité d'eau très chaude;
- 4) les parties de la norme ACNOR F379.1-M1985 qui visent le dépassement de la température et la protection contre l'ébouillantage sont essentiellement valables et n'appellent que quelques précisions;
- 5) avec un minimum de changements, la norme CAN 3-B125-M85 conviendrait pour tester les soupapes des chauffe-eau solaires résidentiels.

Il est recommandé d'examiner les soupapes anciennes pour s'assurer qu'elles fonctionnent aussi bien que les neuves. Il est également recommandé de tester, en simulation, les chauffe-eau solaires résidentiels pour définir les caractéristiques techniques des soupapes et des dispositifs de contrôle de la température maximale. Il serait bon de tester aussi les matériels prometteurs. Les fabricants devraient perfectionner les soupapes dotées d'un dispositif de contrôle de la température de l'eau d'arrivée.

L'étude décrite ici est importante, car elle fournit des renseignements sur la performance des soupapes et des réservoirs auxiliaires. Son importance est cependant limitée par le petit nombre de tests effectués et par le fait que les soupapes testées étaient neuves. Les données résultant des tests peuvent toutefois former la base d'un travail complémentaire et peuvent servir, en attendant d'avoir des renseignements plus judicieux, à l'établissement des normes, à la conception technique et à la création de produits.

Extrait de "Scald Protection in Solar Domestic Hot Water Systems", étude faite par l'Ontario Research Foundation pour EHR (contrat # 6-6080/01-5Z).

C

1. INTRODUCTION

The outlet water temperature produced by solar domestic hot water (SDHW) systems can vary over a wide range, depending on weather conditions and the size of the load imposed. Under some circumstances water will be heated to temperatures that cause pain and scalding if contact with human tissue is allowed to occur. Figure 1 shows the relationship between water temperature and exposure time, for adult skin, as reported by Emmerson [1]. It shows that at 60°C only 3 seconds exposure causes a first degree burn and that 5 seconds exposure results in a second degree burn. While it is clear that water at 60°C can be dangerous, it is sometimes assumed that, except for the young, the aged and the infirm, people will generally feel pain and end their exposure, to water at this temperature, before scalding occurs.

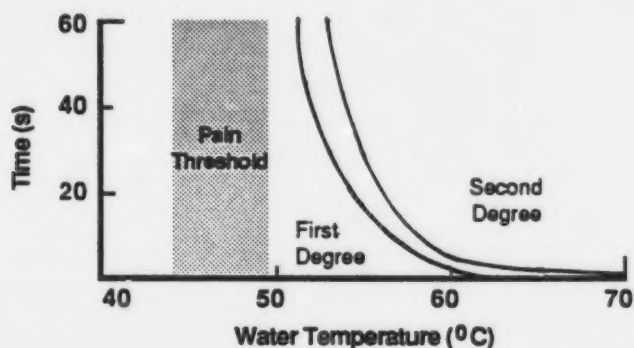


Figure 1: Water Temperature Effects on Adult Skin
Data from A.P. Emmerson and Mark Controls Corp.[1]

CSA Standard F379.1 M1985 [2] requires that the temperature of water available to the user cannot exceed 60°C . While it does not specify exactly how this requirement is to be met, the standard does set limits on the maximum allowable water temperature in the solar storage tank. Clause 8.6.2.3 allows the tank temperature to exceed the scalding temperature (implied to be 60°C) by 15°C if a tempering valve is employed by the system and 3°C if a tempering valve is not used. Similarly, the Canadian Solar Industries Association Solar Energy Product Approval Committee (SEPAC) requirements suggest that an auxiliary tank, separate from the solar storage tank, may be counted on as a buffer that reduces delivery water temperature. The SEPAC requirements allow solar storage water temperature to go as high as 75°C in a preheat system without a tempering valve or 98°C if a tempering valve is employed. The requirements set out by CSA F379.1 M1985 and the SEPAC are only partially in agreement and generally are intuitive rather than being based on reliable test data.

WATSUN program results indicate that the energy delivered by a typical system with a 5.9m^2 collector and 180L storage is reduced about 15% when a 60°C tank temperature limitation is imposed (instead of a 98°C limit). A thermostatic water mixing valve which is claimed by the manufacturer to provide scald protection could be included in a new system for approximately \$100.00 Canadian. Compared to a system controller which dumps 1.35GJ annually, the cost/benefit of the performance improvement is roughly \$75.00 per annual gigajoule. This is an attractive incremental investment if the valve works as intended.

Some data does exist on three low cost [3] (\$10 - 20 U.S.) tempering valves tested by Farrington [4]. These valves displayed a strong delivery temperature dependence on the supply temperature. The delivery temperature changed up to 30°C with a 44°C change in supply temperature leaving the prime responsibility for scald protection with the user. The transient results presented in the same report are questionable as the author states:

"The tempering valves approached the setpoint within 20 seconds of operation. However, the response time of the thermocouple measuring the tempered water was also about 20 seconds, which means that the tempering valves may have approached the setpoint sooner, and also that the thermocouple may not have registered the temperature excursions properly".

In summary, high maximum storage tank temperatures, while good for thermal performance, increase the risk of user scalding. Existing data on the performance of tempering valves and auxiliary tanks used as buffers does not provide a sound basis for revision of the related sections of CSA F379.1 M1985 or modification of the policy of the SEPAC.

2. OBJECTIVES

The objectives of this project were:

- (1) To experimentally evaluate the performance of tempering valves in terms of their ability to prevent scalding water from being delivered to the user;
- (2) To experimentally determine the effectiveness of an auxiliary hot water tank (as used in a preheat SDHW system) in preventing scalding water from the solar tank being delivered to the user;

- (3) To find, review and evaluate existing standards dealing with tempering valves regarding their suitability for the SDHW system application;
- (4) To develop an accelerated aging procedure that would make possible the early testing of tempering valves in an aged condition;
- (5) To make recommendations on the scald protection related sections of CSA F379.1 based on information gathered in this project and a review of the standard.

3. REVIEW OF RELATED STANDARDS

CSA Standard B125-1975, Plumbing Fittings, [5] which includes in its scope "automatic compensating valves (domestic)", was obtained and reviewed. During the course of this work, however, it was superseded by CAN 3-B125-M85, [6] Plumbing Fittings, which was also reviewed. As these two Standards are very much alike, only the current version is described here (with references to relevant differences between the two).

The 1986 American National Standards Institute (ANSI) Catalogue was searched. As a result, two standards that were developed by the American Society of Sanitary Engineering (ASSE) in 1973 and 1976 and approved by ANSI in 1979 were found and reviewed:

- (1) Performance Requirements for Individual Shower Control Valves Anti-Scald Type, ANSI/ASSE Standard No. 1016-1979 [7];
- (2) Performance Requirements for Thermostatic Mixing Valves, Self Actuated for Primary Domestic Use, ANSI/ASSE Standard No. 1017-1979 [8].

Two related ASTM documents were also obtained and reviewed:

- (1) Standard Consumer Safety Specification for Scald Preventing Devices and Systems in Bathing Areas, ASTM Designation: F444-78 [9];
- (2) Standard Consumer Safety Specification for Thermal-Shock-Preventing Devices and Systems in Showering Areas, ASTM Designation: F445-78 [10].

The Canadian Standards Association, the Standards Council of Canada and the Plumbing Manufacturers Institute (U.S.A.) were also contacted to determine if other related standards were available. Additional relevant standards were not found.

3.1 CAN 3-B125-M85 Plumbing Fittings

CAN 3-B125-M85 is a comprehensive standard that addresses such subjects as design requirements, corrosion resistance, thermal cycling, wear, installation and use loading for a wide range of plumbing fittings, including automatic compensating valves. It defines an automatic compensating valve (ACV) as "a device supplied with hot and cold water that provides a means of automatically maintaining the selected outlet water temperature". As B125 places specific requirements on ACV's, it may be considered to be defining a subset of the more general term, tempering valve (or mixing valve). An ACV may be an automatic pressure compensating valve (APCV) or an automatic thermostatic compensating valve (ATCV). Both types of valves must be able to deliver relatively constant temperature water while significant changes in temperature and pressure are imposed on the hot and cold water supplies. The APCV is tested with large pressure

changes imposed while the ATCV is tested with smaller pressure changes as well as temperature changes imposed. Both types of valves are required to reduce the discharge flow rate from 10 l/min to 1.5 l/min or less within 5 seconds of the cold supply line being closed. In B125-1975 this was referred to as the "anti-scald feature" but in CAN 3-B125-M85 all reference to scald prevention has been removed and the requirement is simply entitled "Supply Line Pressure Loss". Since fluctuations in solar DHW system outlet water temperature are the concern in this study, it is the ATCV which is of interest here.

The requirements that an ATCV must meet are summarized below.

- (1) Various aspects of the valve, including workmanship, serviceability, fasteners, tolerances, requirements for metal and plastic parts, marking, etc. are specified.*
- (2) Test requirements include:
 - a) Corrosion resistance (when tested with a salt fog (spray) for 96 hours.*
 - b) Thermal cycling for non-metallic parts.*
 - c) Organic finish degradation, adhesion and erosion.*
 - d) Lifewear: for ACTV's the temperature control dial is turned through its full operating range at 5 cycles/minute for 20,000 cycles and the valve is operated with cold (5 to 20°C) and hot water ($80 \pm 3^\circ\text{C}$) supplied to the hot inlet of the valve in sequence for an additional 80,000 cycles.

* As is the case for all fittings covered by the Standard

- e) Pressure: For leakage at any temperature between 5 and 80°C at 1400 kPa for one minute with the valve closed and at 700 kPa for five minutes with the valve open and the outlet blocked. For burst at 3500 kPa for one minute.
- f) Flow Rate: With a supply pressure of 140 ± 5 kPa the minimum flow rate is 9 l/min.
- g) Temperature Control: Discharge temperature must remain within the limits stated in Table 1 (relative to an initial discharge water temperature of about 40°C) when:
 - i) cold water supply line pressure is varied $\pm 20\%$
 - ii) hot water supply line pressure is varied $\pm 20\%$
 - iii) hot water supply temperature is varied $\pm 15^\circ\text{C}$ (around the initial setpoint of $63 \pm 3^\circ\text{C}$)

These supply variations are imposed independently and rapidly in each individual test.

- h) Supply Line Pressure Loss: The discharge (tempered) flow rate must drop to 1.5 l/min within 5 seconds of the cold water supply being shut off (rapidly).

Table 1
Allowable Variations in Discharge Temperature -
Thermostatic Compensating Valves [6]

Nominal Size	20% Pressure Fluctuations with Supply Temperature Constant	+15 to -15°C Change in Hot Water Supply Temperature, with Supply Pressure Constant
NPS-1/2	$\pm 1.9^\circ\text{C}$	$\pm 2.5^\circ\text{C}$
NPS-3/4	$\pm 3.1^\circ\text{C}$	$\pm 3.6^\circ\text{C}$
NPS-1	$\pm 3.9^\circ\text{C}$	$\pm 4.4^\circ\text{C}$

The ATCV must also have a means of limiting hot water temperature selection.

In its current form the Standard does not explicitly state if it applies to ACV's that are intended for use at the hot water source or at the user end of the supply system or both.

The Standard does not specify requirements for the ACV test apparatus and does not indicate the frequency at which data must be recorded.

3.2 ANSI/ASSE Standard No. 1017-1979 Thermostatic Mixing Valves. Self Actuated for Primary Domestic Use

This Standard applies specifically to mixing valves intended for primary use (i.e. at the source of hot water rather than an end use such as in a shower stall) in controlling line water temperatures so that the user is protected against possible injury from excessive water temperature.

It requires that valves be adjustable over their operating range (which is 38 to 60°C or some smaller range that is clearly noted) with hot water inlet temperatures between 49 and 82°C and cold water inlet temperatures between 4 and 21°C. Performance testing requirements include:

- a) Hydrostatic Pressure Test for permanent distortion or leakage through the valve body at 2069 kPa.
- b) Temperature Control (for domestic flow rates) within $\pm 2^{\circ}\text{C}$ of a 49°C temperature setting* when:

- i) cold water supply line pressure is reduced by 50% (at 100% and 20% of flow capacity);
- ii) hot water supply line pressure is reduced by 50%;
- iii) hot water supply temperature is increased to 93°C (for 5 minutes);
- iv) hot water supply temperature is reduced to 52°C (from the initial setpoint of $63 \pm 3^\circ\text{C}$) while the cold water supply temperature is adjusted to 3°C from an unspecified "available supply temperature".

This test is performed with supply pressures of 310 kPa and 862 kPa and before and after 5 minutes of hot water supplied at 107°C.

- c) Flow rate is at least 24 l/min with supply pressure of 310 ± 35 kPa.

*While the test is carried out only at the 49°C discharge temperature, the Standard "requires" that the mixed water temperature be automatically maintained within $\pm 2^\circ\text{C}$ at any temperature setting.

The Standard includes a piping schematic for testing valves but does not specify the frequency at which data must be recorded.

3.3 ANSI/ASSE Standard No. 1016-1979 Individual Shower Control Valves Anti-Scald Type

This Standard applies only to individual shower mixing valves which are either:

- (1) Thermostatic type which automatically regulate the shower water temperature or
- (2) Pressure balancing type which automatically respond to and correct for fluctuations in cold and hot water pressures. This type of valve (equivalent to the APCV) is not considered here. It applies to valves of the 0.5 inch nominal size with minimum capacity of 24 ± 8 l/min.

Aside from the products to which they apply, ANSI/ASSE Standards 1016 and 1017 contain many common requirements.

Since shower control valves are not the focus of this study, only the significant differences will be highlighted here. In Standard 1016 the temperature control requirement is tighter at $\pm 1.5^{\circ}\text{C}$, test temperature is lower at 38°C and an "anti-scald performance capabilities" test is added. This requires that when the cold supply fails, the hot supply is shut down to less than 6% of the rated flow "before the shower water temperature changes".

3.4 ASTM F444-78 Standard Consumer Safety Specification for Scald-Preventing Devices and Systems in Bathing Areas

This consumer safety specification established "the necessary requirements to ensure safety from scalds for both the normal user capacity and limited user capacity of some aged, infirm or young". It is intended that these requirements be met through the use of available devices and plumbing system designs. The document makes no attempt to specify reliability and testing of these devices and systems, but refers this need to organizations such as ANSI and the ASSE.

This consumer safety specification requires that for scald-preventing devices:

- (1) Materials that are employed resist deterioration (in the environment to which they are exposed) so that intended performance is not adversely affected and those materials in contact with the water cannot be of a type that could contaminate it.
- (2) The maximum allowable outlet temperature is 49°C and if this temperature is exceeded the flow must be automatically reduced to 2.2 l/min in 5 seconds or less.
- (3) Devices and systems will not be adversely affected by a supply pressure of 862 kPa.
- (4) Devices must be packaged with full installer's instructions for installation adjustment and maintenance (where required) and user's instructions that describe its operation and care.
- (5) Clear markings must be provided for temperature controls.

3.5 ASTM F445-78 Standard Consumer Safety Specification for Thermal-Shock-Preventing Devices and Systems in Showering Areas*

This consumer safety specification establishes "the necessary requirements to ensure safety from thermal shock during showering for both the normal user capacity and limited user capacity of some aged, infirm or young".

*The definitions of "Bathing Area" in F444-78 and "Showering Area" in F445-78 are the same. They are therefore taken to be interchangeable.

Since F445-78 has a great deal in common with F444-78 the latter is summarized by comparison to the former. While both documents specify maximum allowable outlet temperature to be 49°C, F445-78 makes no allowance for this temperature to be exceeded (see 3.4 (2)). This document also requires that fluctuations in discharge water temperature be automatically controlled to $\pm 2^\circ\text{C}$ of the adjusted temperature. The materials, pressure, instruction and marking requirements are essentially the same in both documents.

3.6 Discussion of Reviewed Standards

Standard CAN3-B125-M85 leaves the reader with the impression that it is a relatively well thought out document. The requirements for ATCV's are so stringent that only four manufacturers have them included in the CSA list of approved plumbing products [11]: Crane Canada Inc., Karrer, Weber and Co. Ltd.; MCC Powers Process Controls; and Rada Mechanical Products Ltd.

If the ACTV test was to be applied to valves for SDHW systems, their performance should be tested at higher inlet water temperatures (above the currently used 79°C) and some consideration should be given to the highly intermittent (occasional) nature of the tempering requirement.

Both of the ANSI/ASSE standards impose even more stringent requirements on outlet water temperature control than the CSA standard does, making it less likely that moderately priced valves will meet their requirements. The ANSI/ASSE Standard No. 1016-1979 is considered to be closely related but not directly applicable to the SDHW system need, because it applies only to the shower control valves (shower control valves of course can not practically meet the requirement for kitchen and bathroom sinks or

laundry tubs). Also the installation of a valve at each possible load point is likely to be considerably more expensive than a single valve for primary use. An indication of the difficulty in meeting the requirements was found in a manufacturer's advertising brochure that stated: "it's the first and only valve that meets the ASSE Standard 1016". The ANSI/ASSE Standard No. 1017-1979 written for valves that could be used in SDHW systems, but as in the case of the CSA standard, consideration of the highly intermittent nature of the tempering requirement should be added for the solar application.

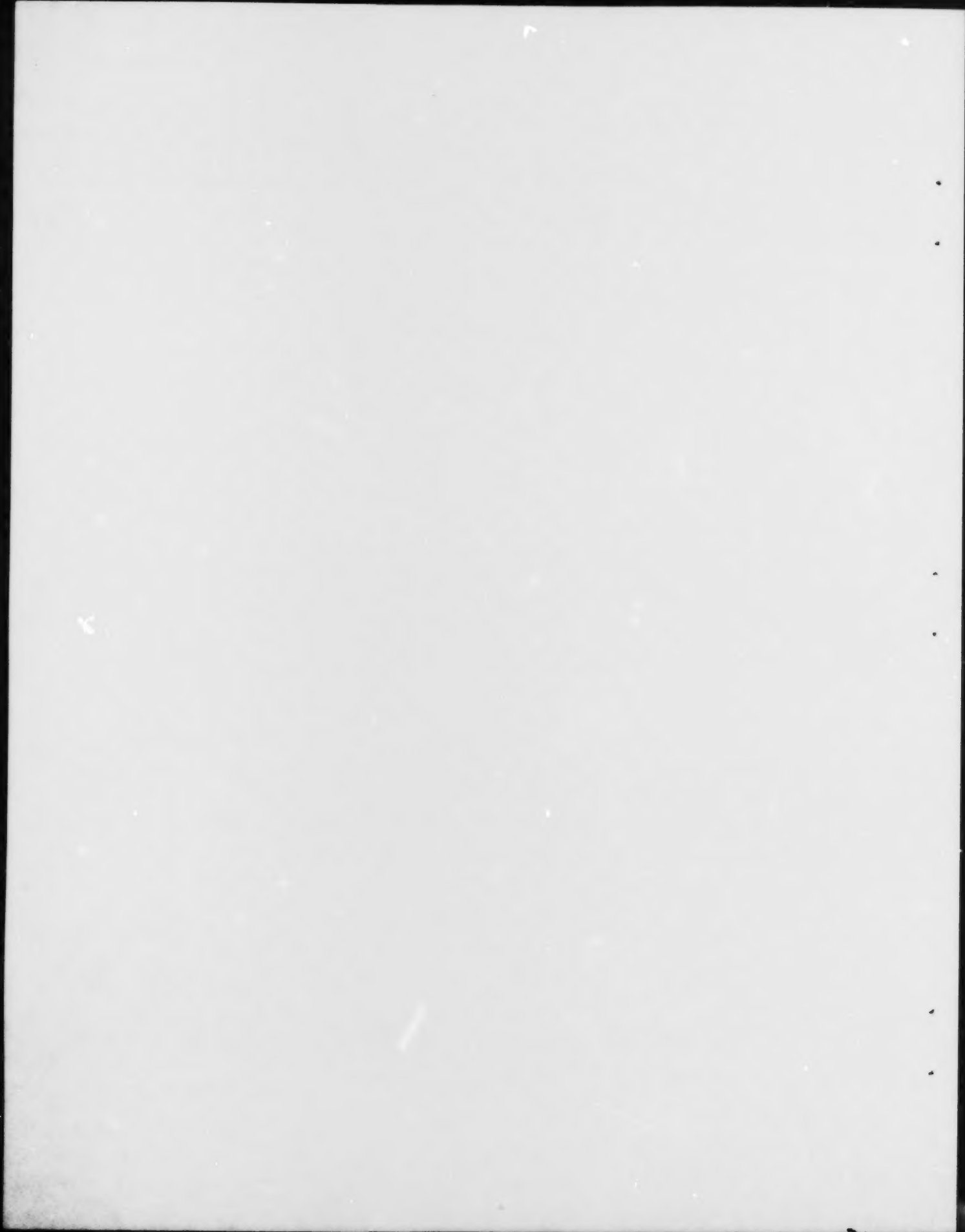
The ASTM documents define the requirements that must be met for safe application of the hardware which have been adopted for the most part in the ANSI/ASSE standards. The maximum allowable temperature is given as 49°C (which may be exceeded only if the flow is reduced to 2.2 l/min in 5 seconds or less).

4. TEMPERING VALVE TESTING

An ideal test for a tempering valve intended for use in an SDHW system would probably involve installing it in an actual system and closely monitoring the outlet or delivery water temperature while subjecting the system to a wide range of solar energy inputs, load sizes and load draw patterns. Such a test is not practical in terms of the amount of time that would be required to vary each of the input parameters over the desired range. A more pragmatic approach which allows relatively fast and easily repeatable tests was taken in the design of the method used here.

4.1 Method

In this section the valve selection, the tempering valve test apparatus, and the test procedure are described.



4.1.1 Valve Selection

Information published by Farrington [4] did not include product names but the valves he tested were described as being low cost [3]. The results suggested that more expensive valves might need to be investigated to find good performance. It was concluded that low, mid and high priced valves should be selected for test to assess the likely range of available performances. Six different models of tempering valve were selected and purchased in pairs. A seventh valve, the MCC Powers Photoguard 440, owned by ORF and used as laboratory equipment, was made available for comparison in the tests. It will be referred to as the Hydroguard 420, which is technically identical, and intended for service water tempering. It has a current retail price of \$459. so only a single unit was tested. The valves selected and their costs are listed in Table 2.

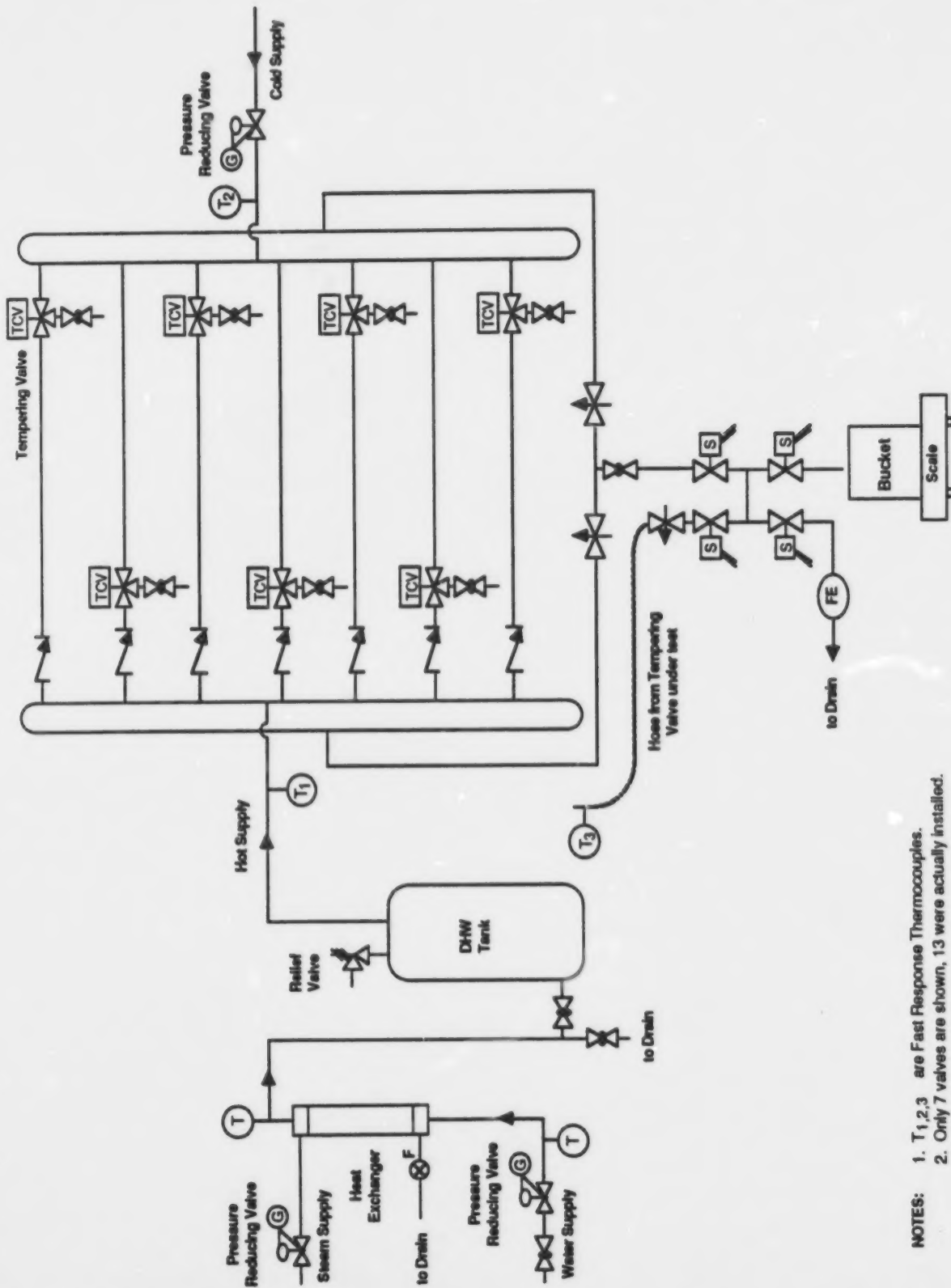
Table 2
Tempering Valves Selected for Testing

Manufacturer	Model	Cost (\$)¹
Watts	70A	44
Cash Acme	TMA-3	29
Sparco	TV120	21
Sparco	Aquamix AM100	64
Amot	CMAT	138
H & H Precision Products	V220-1	118²
MCC Powers	Hydroguard 420	459³

- Notes:
1. Cost to ORF. Federal Sales Tax and Duty included, Provincial Sales Tax excluded
 2. Excluding Customs Brokerage
 3. Current Price

4.1.2 Apparatus

A tempering valve test facility was designed and built and is shown schematically in Figure 2 and in photographs in Figure 3. A computer based test control and data acquisition system was part of the apparatus, but does not appear in the Figures. The test rig consisted of a means of supplying hot water at nearly constant temperature and a nearly constant temperature supply of cold water from the mains. Figure 2 shows the supply connections to the hot and cold water manifolds. Each manifold had a bleed line with metering valve which allowed water to flow to the drain at a constant preset rate to maintain a fixed manifold water temperature while standing by prior to a test. The thirteen (6 pairs plus one) tempering valves were connected to the hot and cold manifolds via the appropriate supply ports. A check valve was installed in each hot supply line to prevent cold water from passing through inactive tempering valves into the hot manifold. One tempering valve of each pair was located close to the cold manifold to help maintain the valve at a low temperature, representative of installations where the valve would tend to sit at or below ambient temperature when not in use. The other valve of each pair was located close to the hot manifold to help keep it at a relatively high temperature, representative of installations where the valve would tend to sit at temperatures close to the tank outlet temperature when not in use. These two starting conditions/locations are subsequently referred to as cold soak and hot soak respectively. On the delivery or mixed port of each tempering valve a globe valve was installed to act as a shut off on each of the valves not being tested. A fast response thermocouple ($\tau = 0.02s$) allowed fast and accurate measurement of the delivery water temperature for the tempering valve under test. A flexible hose led to a needle valve and a bucket on an electronic scale which allowed presetting and test measurement



- NOTES:
1. T₁, T₂, T₃ are Fast Response Thermocouples.
 2. Only 7 valves are shown, 13 were actually installed.

Figure 2. Schematic of Tempering Valve Test Facility

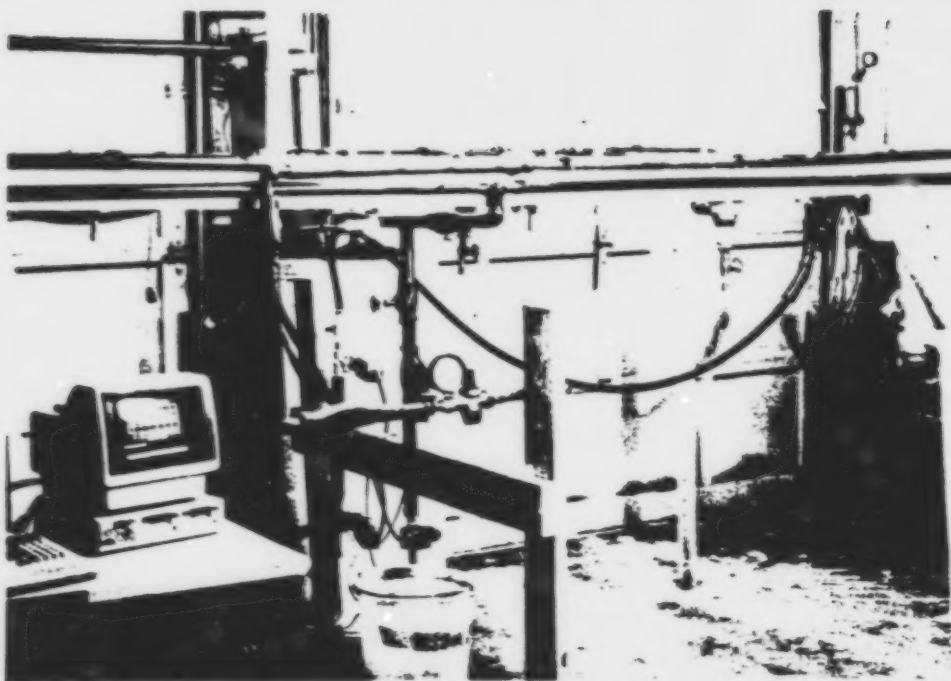
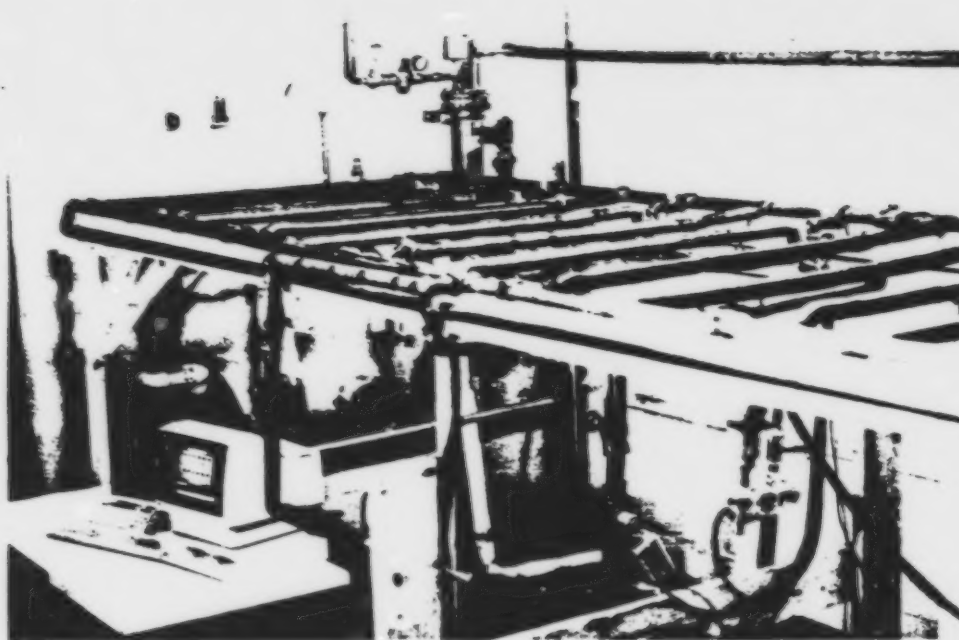


Figure 3: Photographs of Tempering Valve Test Facility

of the delivery water flow rate. Solenoid valves allowed bleed water flow from the supply manifolds to the drain to be shut off in favour of water flow through the tempering valve under test to the weigh-bucket. A Hewlett Packard Series 200 computer was programmed to operate the apparatus in three modes:

- (1) test set-up
- (2) standby
- (3) test

Under the "test set-up" mode water from the tempering valve, with the outlet hose connected, passed through the flow meter to drain. No water flowed through the bleed lines. Pertinent temperatures and the mixed water flow rate were measured and displayed on the monitor to facilitate adjustments.

In the "standby" mode water flowed through the manifolds, bleed lines and flow meter to drain. Pertinent temperatures and total bypass flow rate were measured and displayed on the monitor.

In the "test" mode water flowed through the manifolds to the valve under test and was collected in a bucket on the weigh scale. The delivery water temperature was measured and recorded at 0.2 second intervals while the two supply temperatures were measured and recorded once a second. The test duration was one minute. Temperature data was then plotted and average flow rate, inlet temperatures and delivery temperature were printed on the screen.

4.1.3 Test Method

A 14 to 28 kPa pressure differential (with cold side pressure higher) was imposed and maintained between the cold and hot manifolds to prevent leakage flows through the check valves. Adjustments were made to the steam supply to achieve the desired 93°C hot water supply temperature to the DHW tank. Once the cold and hot water supply temperatures were achieved and stabilized the valve set-up began.

The flexible outlet hose was attached to the first valve and the computer was instructed to operate the system in the set-up mode. The flow rate through the valve was adjusted to 42/min using the outlet hose needle valve. The tempering valve itself was then adjusted to produce a delivery temperature of 49°C when operating in this steady state condition. This valve setpoint temperature adjustment was performed on each valve in turn, except for the pair of valves manufactured by Amot which were not adjustable. The delivery temperature adjustment achieved in this way remained fixed for all of the 49°C setpoint tests. Once the tempering valves were adjusted, the testing proceeded as follows. The hot supply water temperature was adjusted to the desired value and allowed to stabilize. In set-up mode the valve flow rate was set to the desired value. The system was switched to standby mode and the two manifold outlet needle valves were adjusted to achieve the anticipated test outlet flow rate and temperature (so that significant changes in flow and temperature would not occur when the test was started). For the cold soak valves, cold water was poured over the valve body to reduce its temperature (following set-up) for a repeatable "cold start". For hot soak valves a short period of operation in set-up mode ensured a repeatable "hot start" condition.

A test was then performed. Immediately following the test the collected data was plotted on the screen and reviewed. If necessary the test was repeated. When no problems were detected the above procedure was repeated for the next valve, using the same test conditions. Once each valve had been tested for the first hot supply temperature and flow rate the procedure was repeated for the second flow rate. Following this series of tests the tests were repeated for two other supply temperatures at each flow rate.

The adjustable valves (11 out of a total of 13) were then readjusted (using the procedure described at the beginning of this section) to produce a 60°C delivery water temperature when supplied with 93°C hot water and operated at a flow rate of 4 l/min. These valves were then put through the same series of tests described above with the new setpoints.

4.2 Tempering Valve Test Results

The test results are presented in groups that represent a range of operating conditions for each tempering valve, with one setpoint and one starting condition shown on each plot.

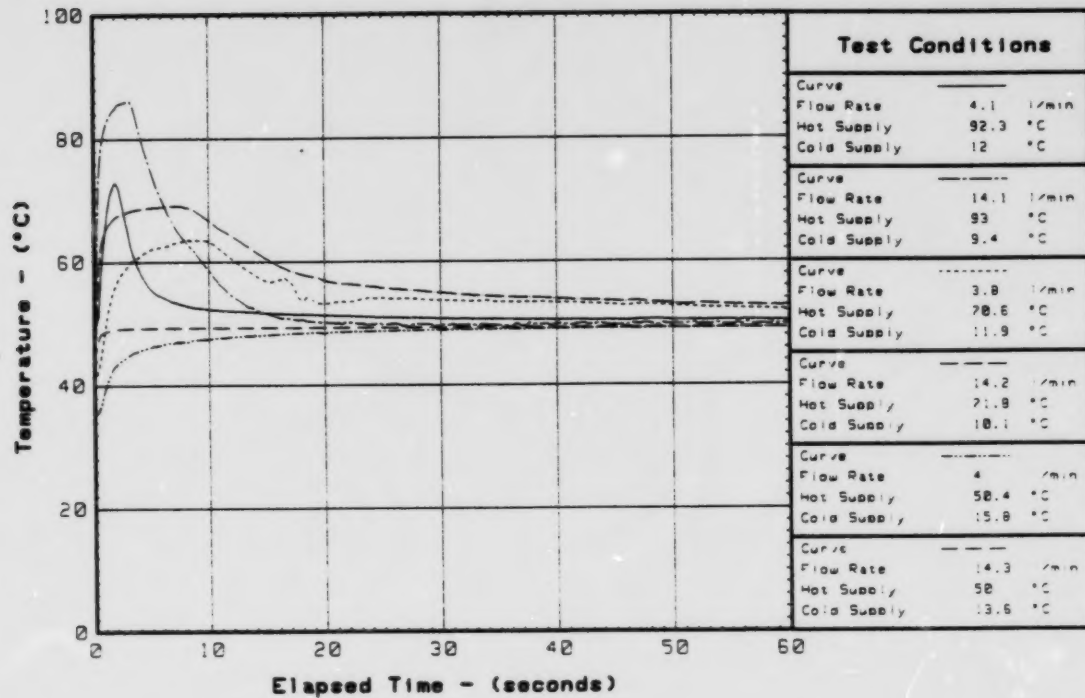
The six curves in a graph therefore represent a range of operating conditions (nominal hot water supply temperatures of 49, 71 and 93°C and nominal load flow rates of 4 and 14 l/min) that one valve might experience after being installed in a SDHW system and having its setpoint adjusted. The two graphs appearing on a page represent the 49 and 60°C setpoints for a given valve and installation location (either hot soak or cold soak as defined in

4.1.2). A discussion of performance of each valve with respect to scald protection, unwanted tempering, preferred installation location and range of acceptable hot water supply temperatures appears in the following sections. In the following discussion it is assumed that the valve is used alone, that is, without other means of scald protection. A critical temperature of 60°C has been defined because of the speed with which scalding can occur with exposure to water at or above this temperature.

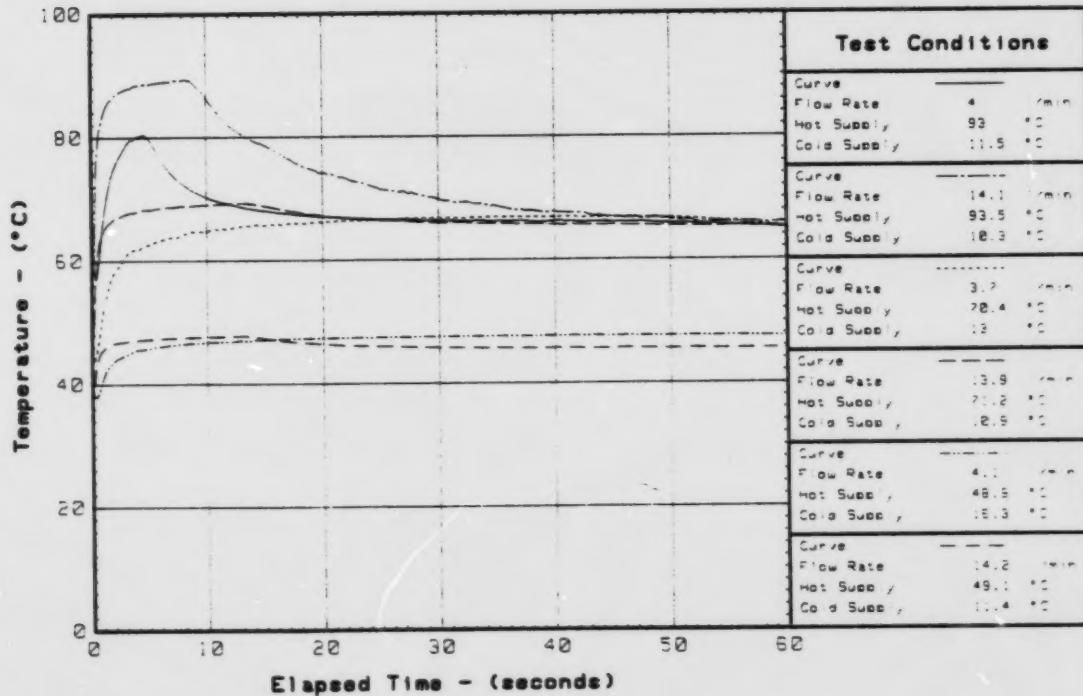
4.2.1 Watts Regulator 70A

The Watts Regulator Model 70A is an inexpensive tempering valve which is frequently specified in Canadian SDHW system packages. Figure 4a shows the measured delivery temperature for this valve when it was operated from the hot soak starting condition and adjusted for a 49°C setpoint temperature. The results for nominal hot water supply temperatures of 93 and 71°C, at both 4 and 14 L/min flow rates show that the delivery water temperature exceeded the critical 60°C temperature for considerable periods of time. This indicates that under these conditions scalding (in this case, second degree burns) could occur. Naturally, the tests using a nominal 49°C hot supply temperature posed no scalding concerns. They did, however, show that unwanted tempering was not a problem with this valve under these conditions.

The performance of the same hot soak valve, but preset to a 60°C setpoint temperature, is shown in Fig. 4b. Generally the peak outlet temperature was higher and the length of time spent above 60°C was greater than for the 49°C setpoint, suggesting an increased risk of scalding is associated with the higher setpoint. When tested at the high flow rate (14 L/min) with 49°C hot supply water this valve displayed a small amount (about 2°C) of unwanted tempering.

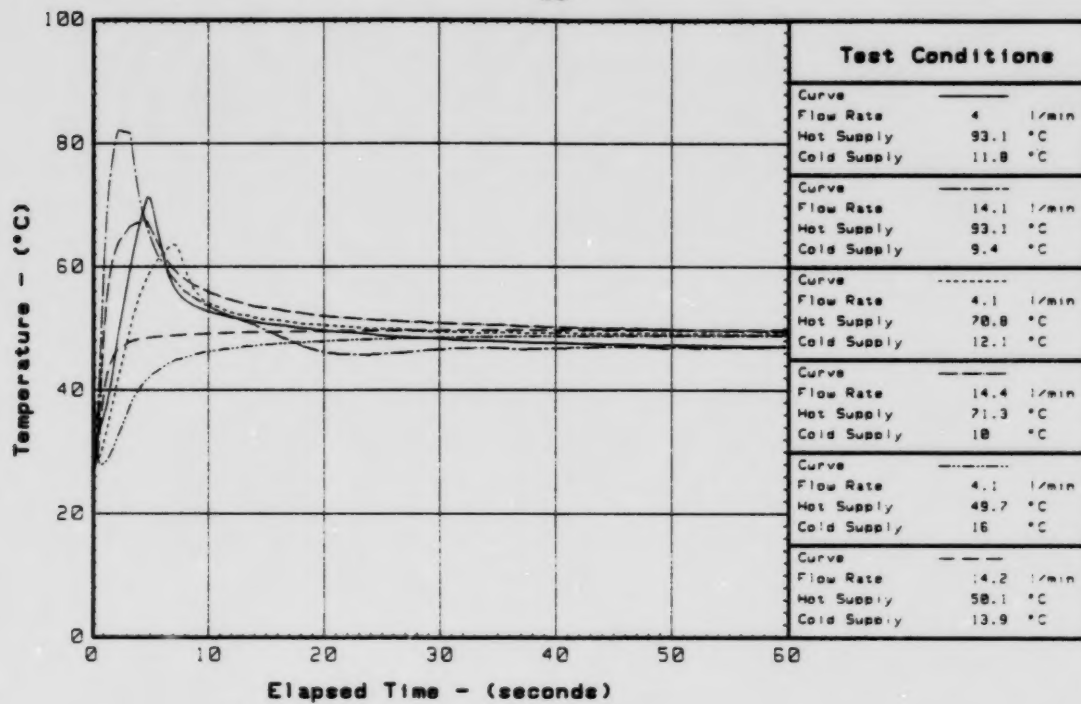


(a) Setpoint Temperature 49°C, Hot Soak

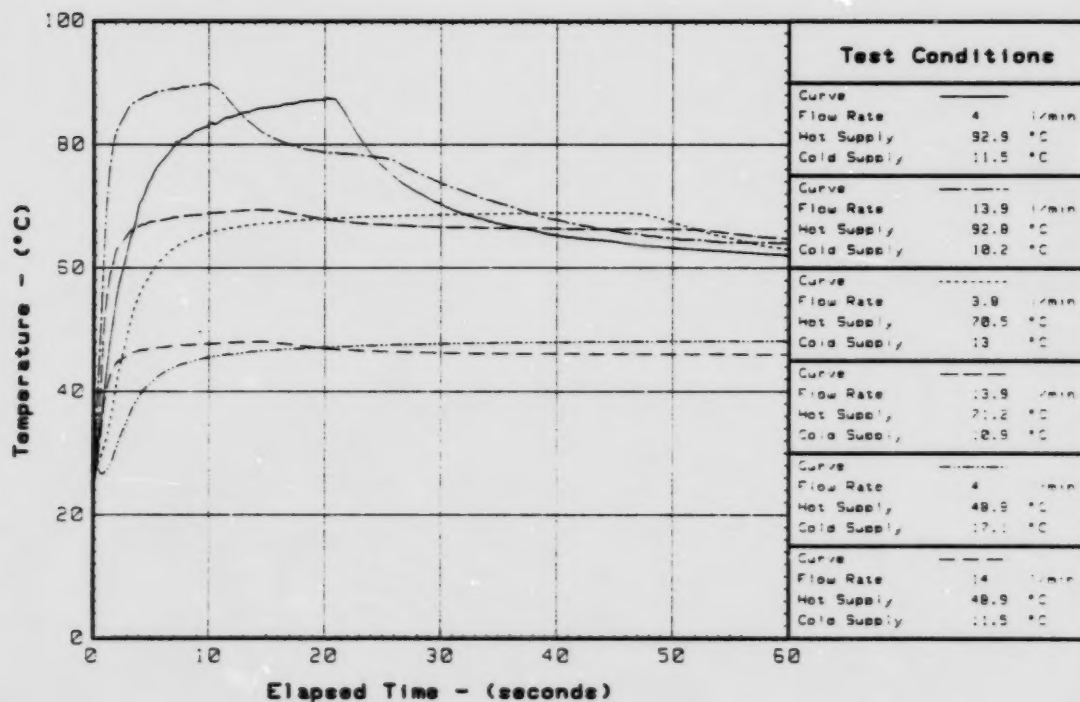


(b) Setpoint Temperature 60°C, Hot Soak

Figure 4: Measured Delivery Temperatures: Watts Regulator 70A



(c) Setpoint Temperature 49°C, Cold Soak



(d) Setpoint Temperature 60°C, Cold Soak

Figure 4: Measured Delivery Temperatures: Watts Regulator 70A (Cont'd)

In the hot soak tests reported above, the peak delivery temperatures were higher and the lengths of time that the delivery temperatures were above the critical temperature were greater for the high flow rate (14 l/min) tests than for the low flow rate (4 l/min) tests.

Performance results for the Watts 70A tempering valve operated from the cold soak starting condition, (but otherwise essentially duplicating those presented above) are shown in Figs. 4c and 4d. For this valve the cold soak, 49°C setpoint results, Fig. 4c, showed somewhat faster response than the corresponding hot soak results shown in Fig. 4a. However, comparison of the hot and cold soak test results for the 60°C setpoint, Figs. 4b and 4d, do not repeat this trend. While the potential for scalding exists at both setpoints, it is much greater for the 60°C setpoint. The cold soak tests also confirmed that, in general, the 14 l/min test condition displayed a greater potential for scalding than did the 4 l/min test condition.

In summary, this valve displayed considerable potential for scalding at 49 and 60°C setpoint temperatures, with 4 and 14 l/min flow rates with hot water supply temperatures of 71 or 93°C. A small amount of unwanted tempering occurred when 49°C water was supplied and the valve setpoint was 60°C. At the 49°C setpoint this valve performed better from the cold soak starting condition, but this was not the case for the 60°C setpoint.

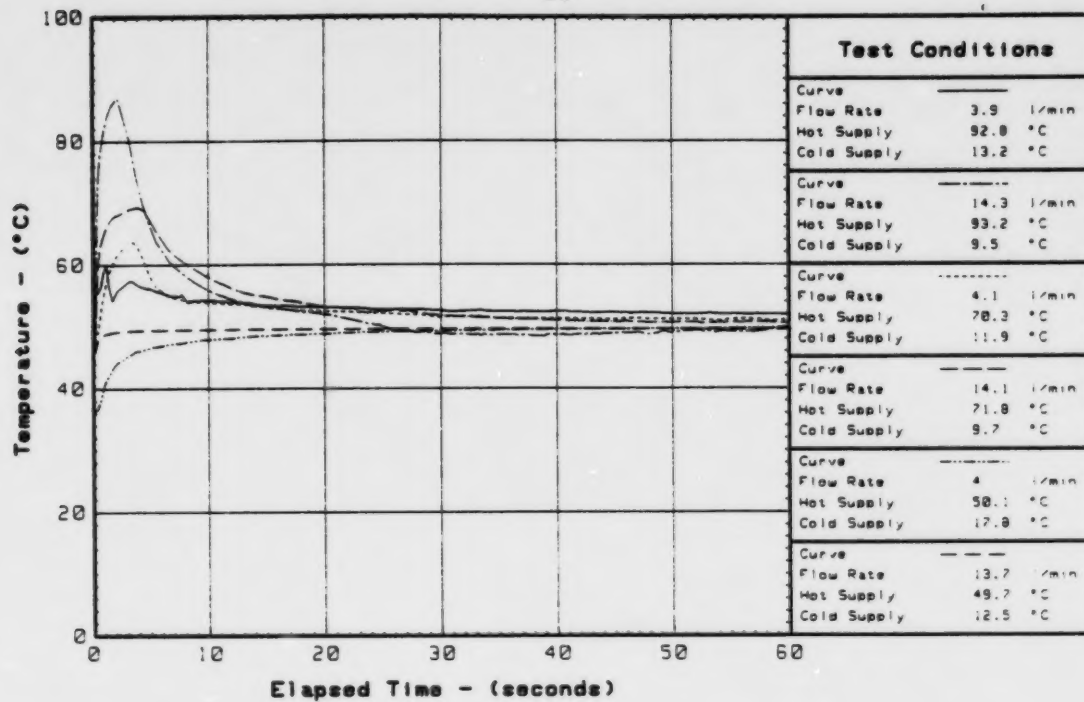
4.2.2 Cash Acme TMA-3

The Cash Acme TMA-3 is an inexpensive tempering valve which physically appears to be almost identical to the Watts Regulator 70A (Section 4.2.1). While the delivery temperature curves for the two valves resemble each other they are substantially different. Figure 5a shows measured delivery temperatures for the Cash Acme valve when it was operated from the hot soak starting condition and adjusted for a 49°C setpoint. When tested with a 93°C hot water supply, the valve showed no scalding potential at the 4 l/min flowrate* and significant scalding potential at 14 l/min. The tests done with 71°C hot water, at both 4 and 14 l/min flow rates show that the delivery water was above the critical temperature for considerable periods of time. This indicates that scalding could occur. The tests using a 49°C hot water supply temperature posed no safety concerns but showed that unwanted tempering was not a problem under these conditions.

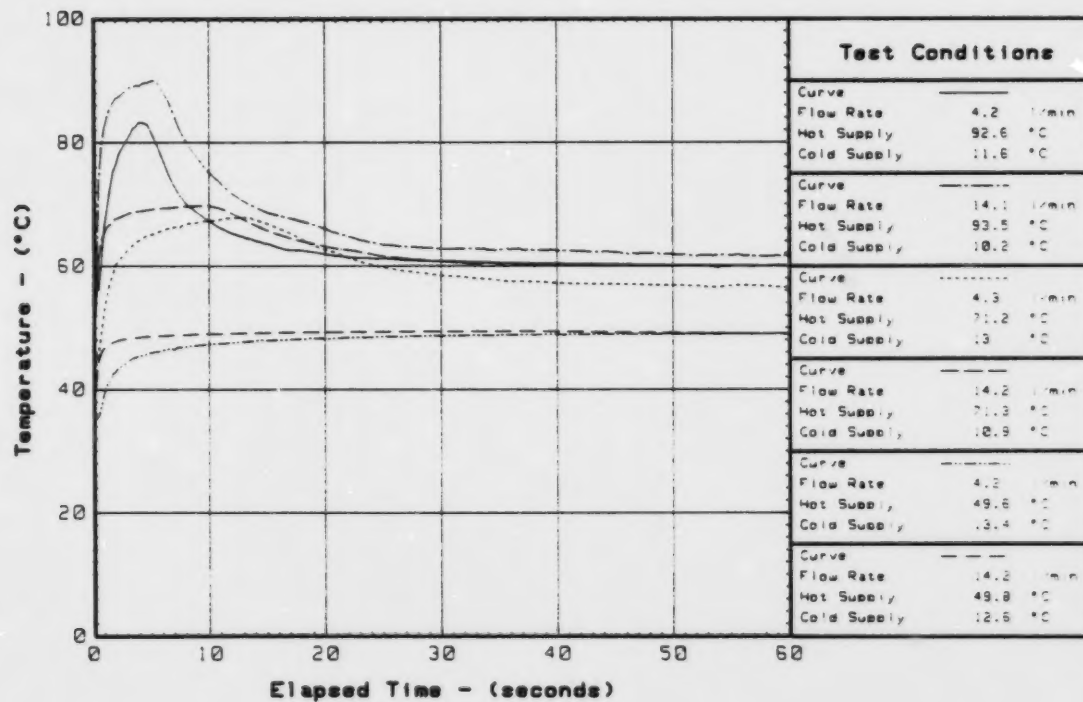
The measured performance of the same hot soak valve, but preset to a 60°C setpoint temperature, is shown in Figure 5b. Generally the peak delivery temperature was higher and the length of time spent above the critical temperature was greater than for the 49°C setpoint, suggesting an increased risk of scalding is associated with the higher setpoint. No unwanted tempering was apparent in the 49°C hot supply test.

In the hot soak tests reported above, the peak delivery temperatures were higher and the lengths of time that the delivery temperatures were above the critical temperature were greater for the 14 l/min flow rate tests than for the 4 l/min flow rate tests.

* This was likely the result of an unusually high hot soak starting temperature.

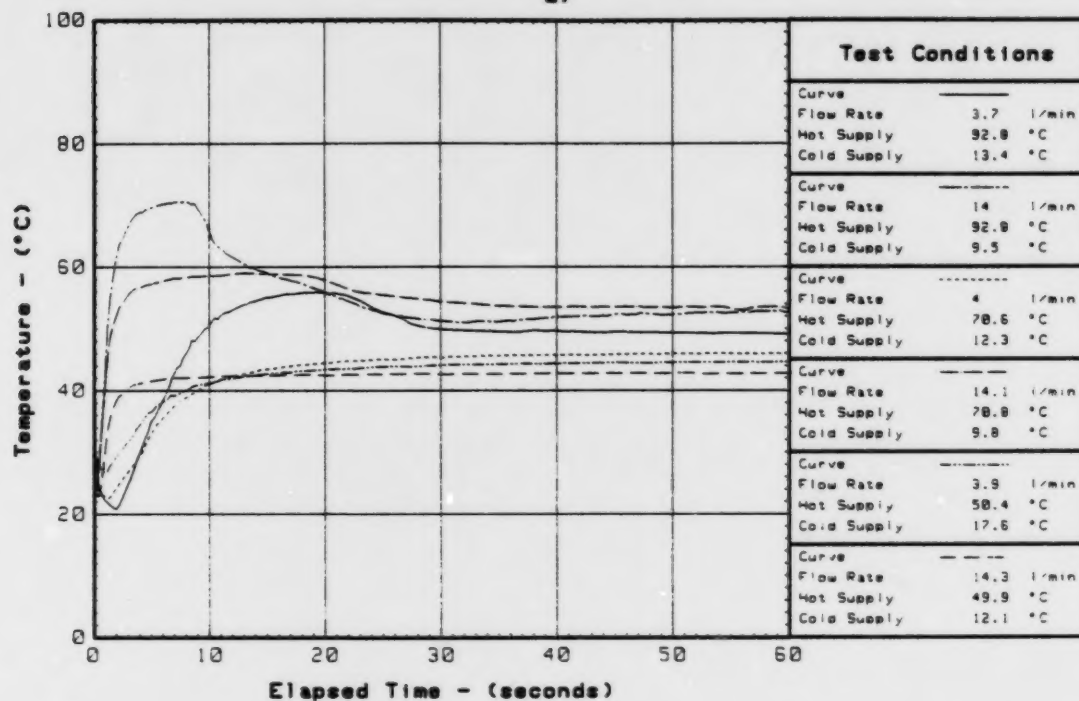


(a) Setpoint Temperature 49°C, Hot Soak

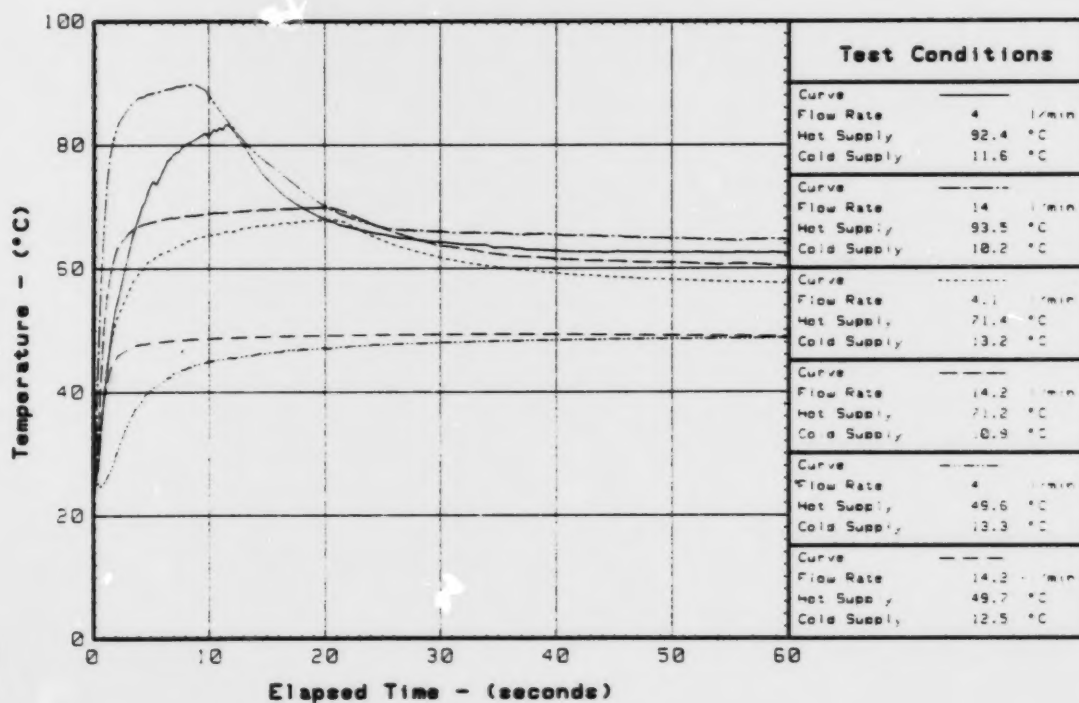


(b) Setpoint Temperature 60°C, Hot Soak

Figure 5: Measured Delivery Temperatures: Cash Acme TMA-3



(c) Setpoint Temperature 49°C, Cold Soak



(d) Setpoint Temperature 60°C, Cold Soak

Figure 5: Measured Delivery Temperatures: Cash Acme TMA-3 (Cont'd)

Performance results for the Cash Acme tempering valve tested from the cold soak starting condition are shown in Figures 5c and 5d. For this valve, the cold soak tests with the 49°C setpoint shown in Figure 5c, showed somewhat lower peak temperatures and slower response than the corresponding hot soak tests shown in Figure 5a. The only cold soak, 49°C setpoint test that displayed scalding potential was the 93°C hot supply, 14 l/min flow rate test. Comparison of the hot and cold soak test results for the 60°C setpoint, Figures 4b and 4d, do not repeat this trend with respect to lower peak temperatures but do display slower response. While the potential for scalding exists at both setpoints, it is much greater for the 60°C setpoint. The cold soak tests also confirmed that, in general, the 14 l/min test condition displayed a greater potential for scalding than did the 4 l/min test condition.

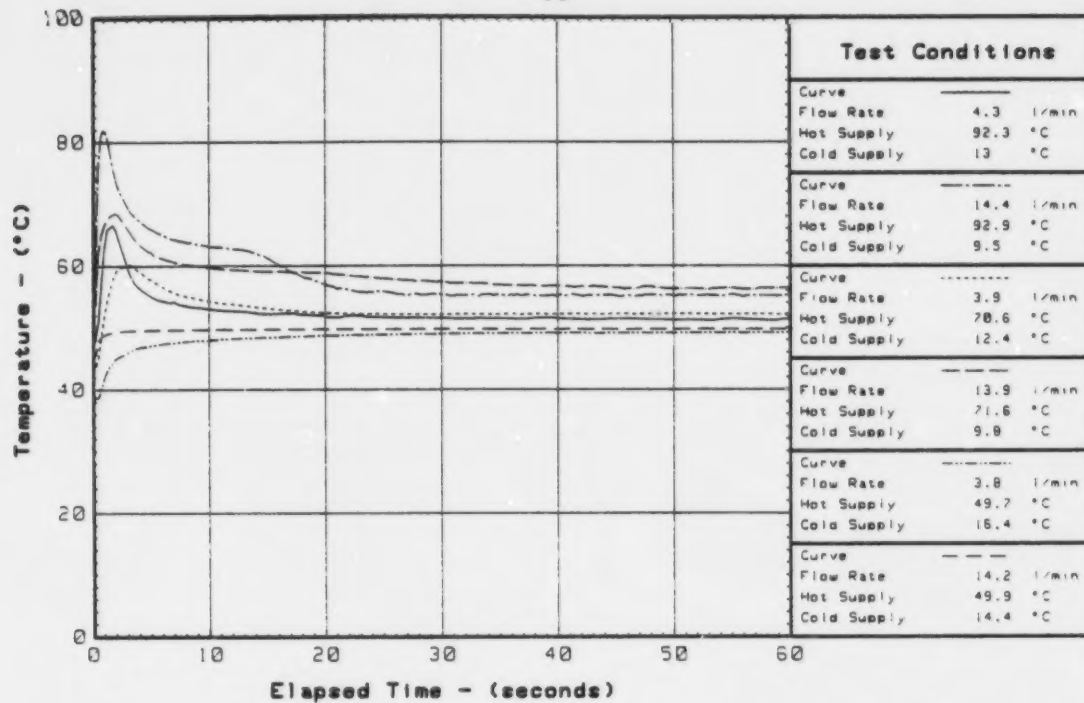
In summary, this valve displayed considerable potential for scalding (although less than the Watts 70A) at 49 and 60°C setpoint temperatures, with 4 and 14 l/min flow rates when supplied with hot water at 71 or 93°C. Some unwanted tempering occurred when 49°C hot water was supplied and the cold soaked valve was set for a 49°C delivery temperature. At the 49°C setpoint this valve performed better from the cold soak starting condition but the hot soak condition is preferred if the 60°C setpoint were to be used.

4.2.3 Sparco TV120

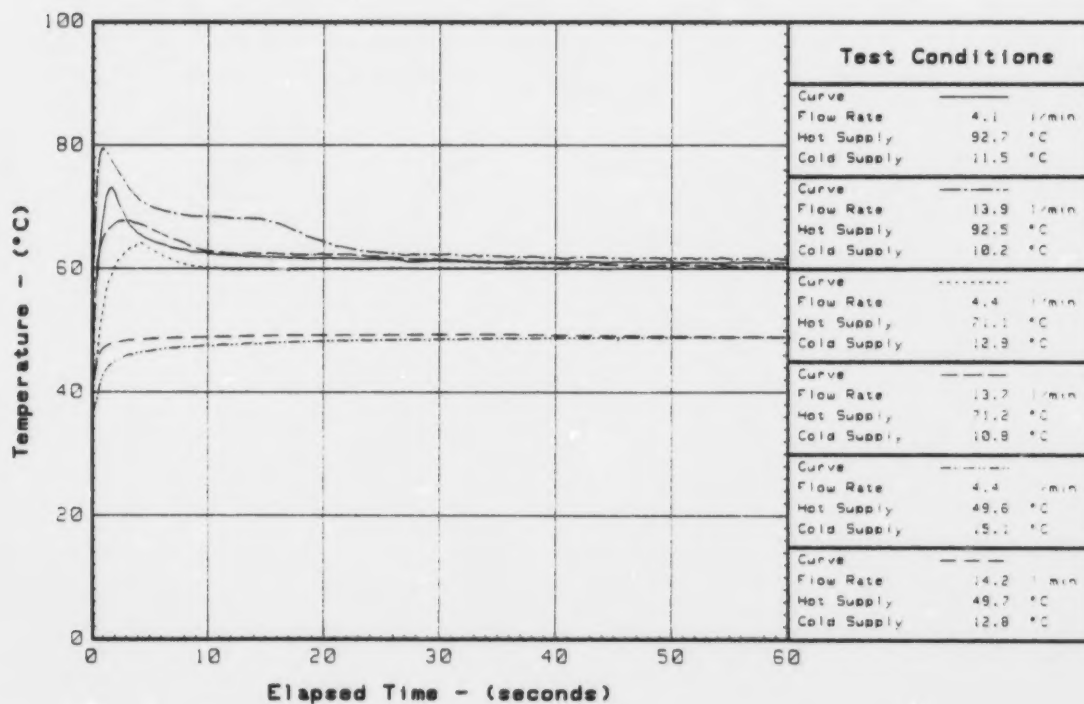
The Sparco TV120 is an inexpensive tempering valve which is similar in appearance to the Watts Regulator 70A and the Cash Acme TMA-3. Figure 6a shows the measured delivery temperatures for the TV120 valve when it was operated from the hot soak starting condition and adjusted for a 49°C setpoint. The results for tests done with a 93°C hot water supply, at both 4 and 14 l/min flow rates and for 71°C hot supply at the 14 l/min flow rate, show that the delivery water was above the critical temperature for considerable periods of time. This indicates that scalding could occur. No potential scalding condition existed during the 71°C, 4 l/min test. The tests using a 49°C hot water supply temperature posed no safety concerns but showed that unwanted tempering was not a problem under these conditions.

The measured performance of the same hot soak valve, but preset to a 60°C setpoint temperature, is shown in Figure 6b. Generally the peak delivery temperature was higher and the length of time spent above the critical temperature was greater than for the 49°C setpoint, suggesting an increased risk of scalding is associated with the higher setpoint. This valve did not display any unwanted tempering in the 49°C hot supply tests.

In the hot soak test reported above, the peak delivery temperatures were higher and the lengths of time that the delivery temperatures were above the critical temperature were greater for the 14 l/min flow rate tests than for the 4 l/min flow rate tests.



(a) Setpoint Temperature 49°C, Hot Soak



(b) Setpoint Temperature 60°C, Hot Soak

Figure 6: Measured Delivery Temperatures: Sparco TV120

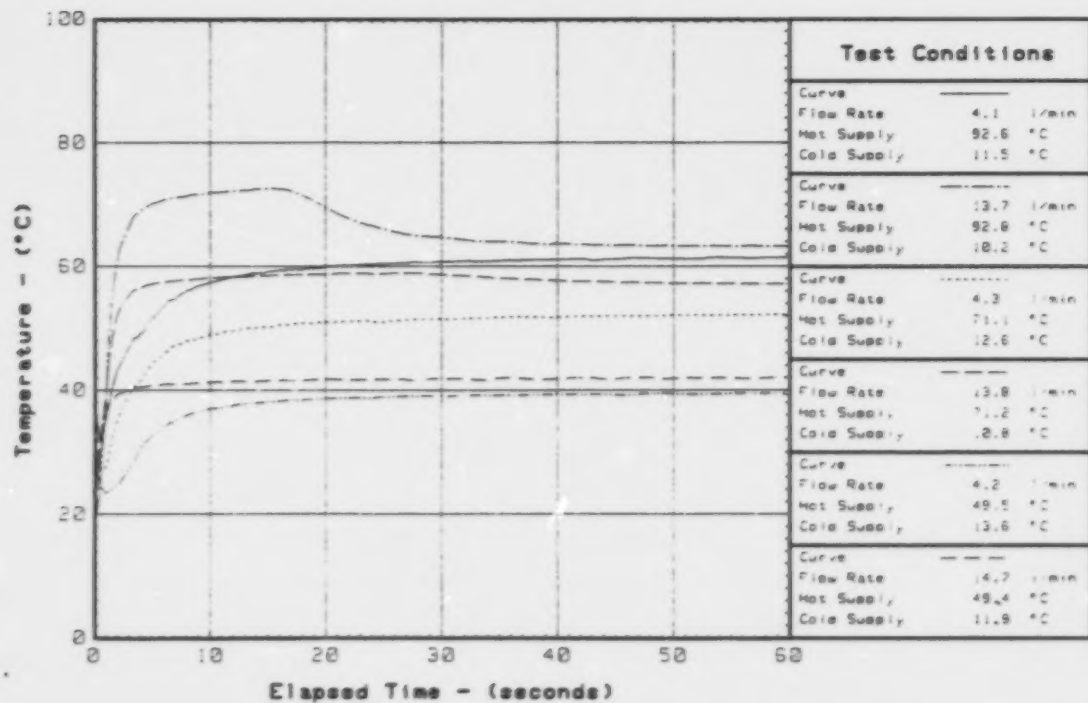
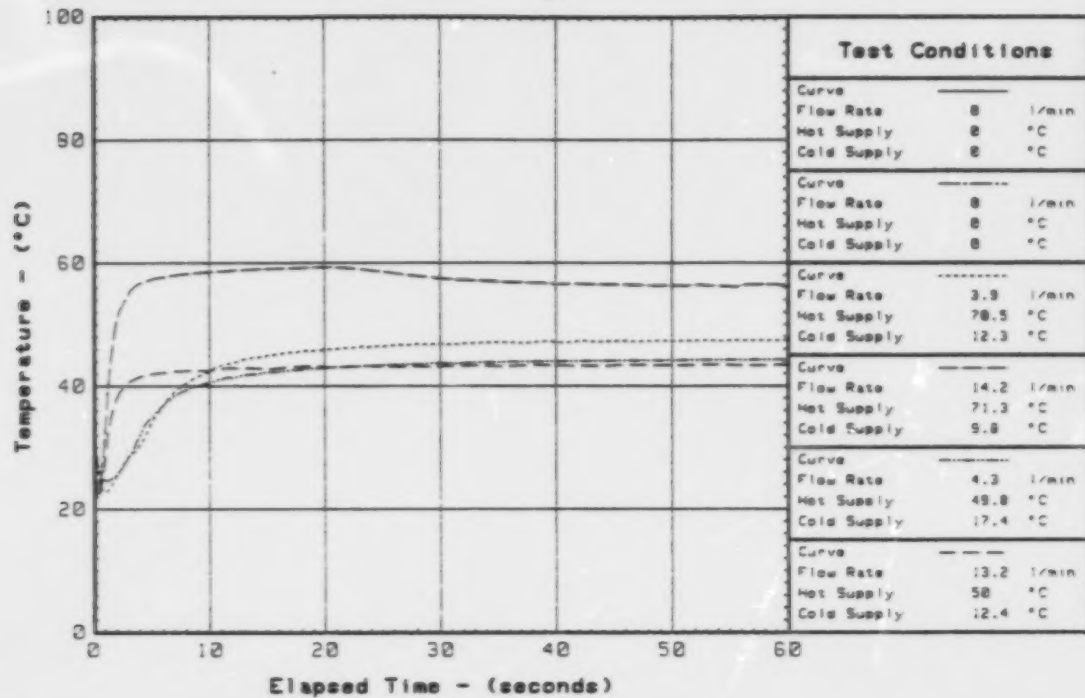


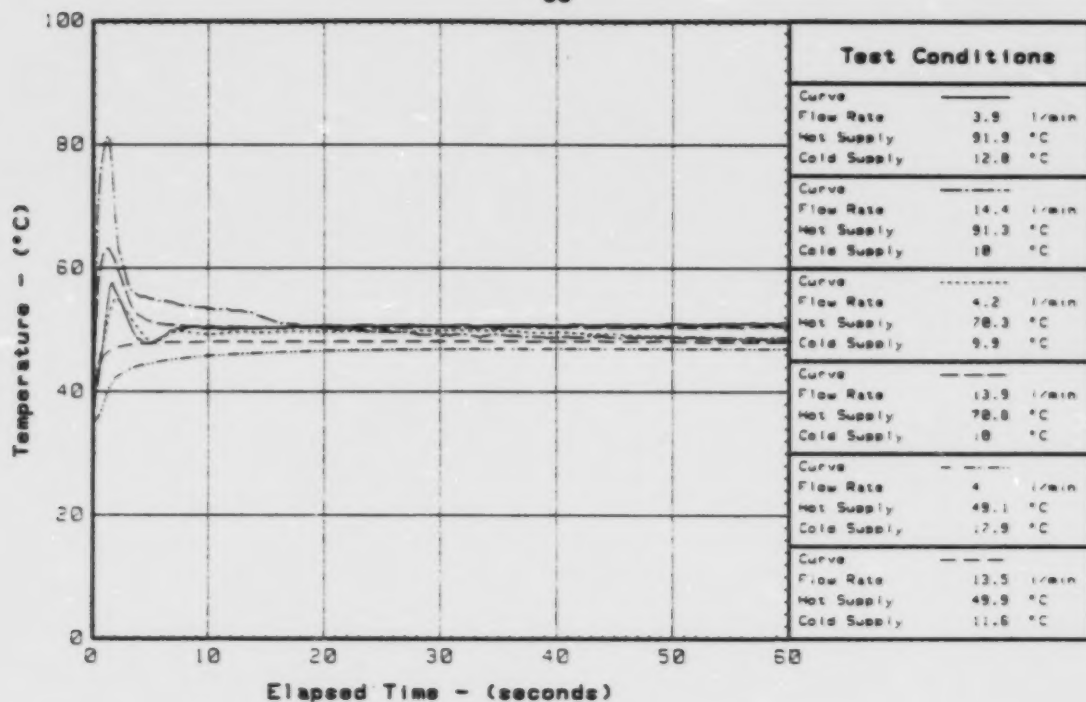
Figure 6: Measured Delivery Temperatures: Sparco TV120 (Cont'd)

Performance results for the Sparco TV120 tempering valve operated from the cold soak starting condition, are shown in Figures 6c and 6d although it is believed that the cold soak valve was defective, affecting the valve's performance. Most of the tests were performed before the problem was discovered. The steady state delivery temperature from the cold soak valve showed a great dependence on both flow rate and hot water supply temperature. This was not the case with the hot soak valve. A subsequent inspection (see Section 6) of the valve did not reveal any obvious reason for the problem.

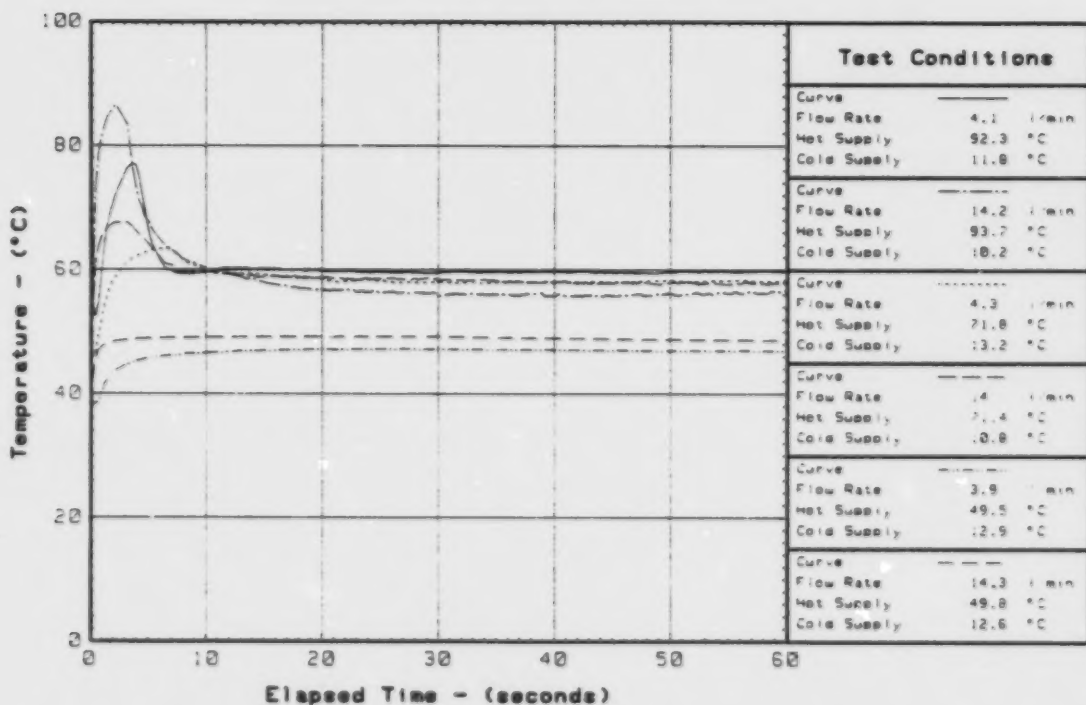
In summary, the hot soak valve displayed considerable potential for scalding at 49 and 60°C setpoint temperatures, with 4 and 14 l/min flow rates, when supplied with hot water at 71 or 93°C. Unwanted tempering was not observed for this valve. Results for the cold soak valve should not be considered valid.

4.2.4 Sparco Aquamix

The Sparco Aquamix is a moderately priced tempering valve. Figure 7a shows the measured delivery temperatures for the Aquamix valve when it was operated from the hot soak starting condition and adjusted for a 49°C setpoint. The tests done with a 93°C hot water supply, and the 14 l/min flow rate produced a delivery water temperature that peaked at about 82°C and stayed above 60°C for about 2.5 seconds. Under this test condition scalding could occur. The 71°C, 14 l/min test condition produced a delivery temperature that peaked about 63°C and stayed above the critical temperature for about 1.5 seconds. This condition is very close to the scalding threshold. None of the 49°C setpoint

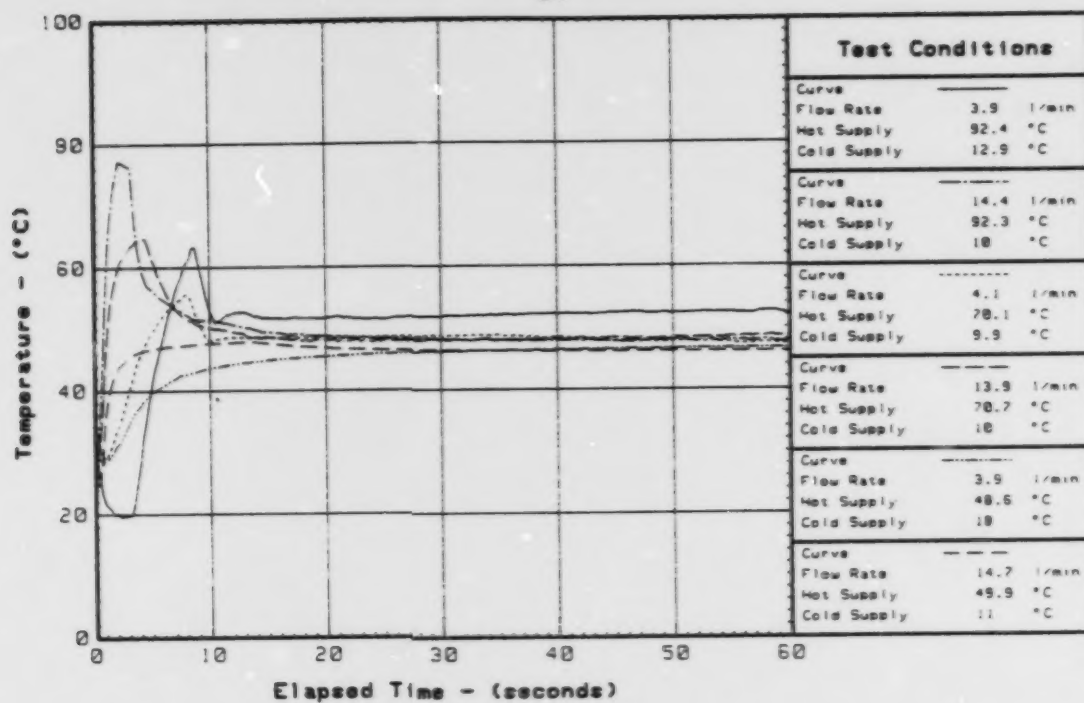


(a) Setpoint Temperature 49°C, Hot Soak

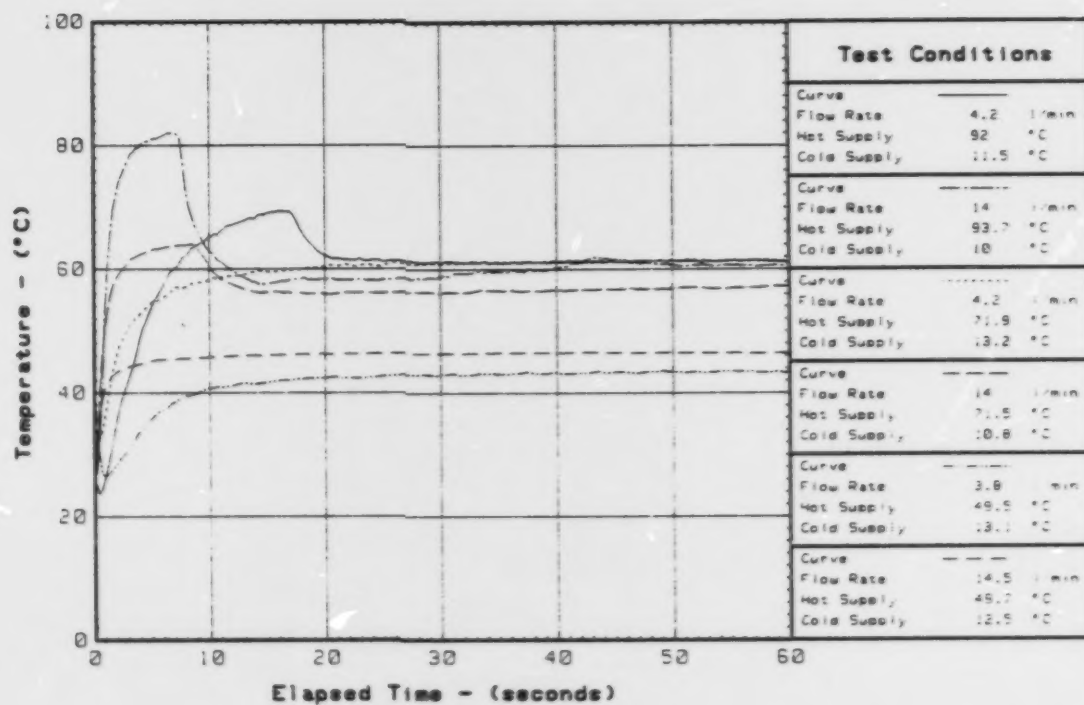


(b) Setpoint Temperature 60°C, Hot Soak

Figure 7: Measured Delivery Temperatures: Sparco Aquamix AM100



(c) Setpoint Temperature 49°C, Cold Soak



(d) Setpoint Temperature 60°C, Cold Soak

Figure 7: Measured Delivery Temperatures: Sparco Aquamix AM100 (Cont'd)



tests at 4 l/min resulted in delivery temperatures reaching 60°C, implying no scalding potential. The tests using a 49°C hot water supply temperature posed no safety concerns, but showed that a small amount (~2°C) of unwanted tempering occurred at the 4 l/min flow rate.

The performance of the same hot soak valve, but preset to a 60°C setpoint temperature, is shown in Figure 7b. Generally the peak delivery temperatures are higher and the lengths of time spent above the critical temperature are greater than for the 49°C setpoint, suggesting an increased risk of scalding is associated with the higher setpoint. When tested at the 4 l/min flow rate with 49°C hot supply water this valve displayed a small amount (~2°C) of unwanted tempering.

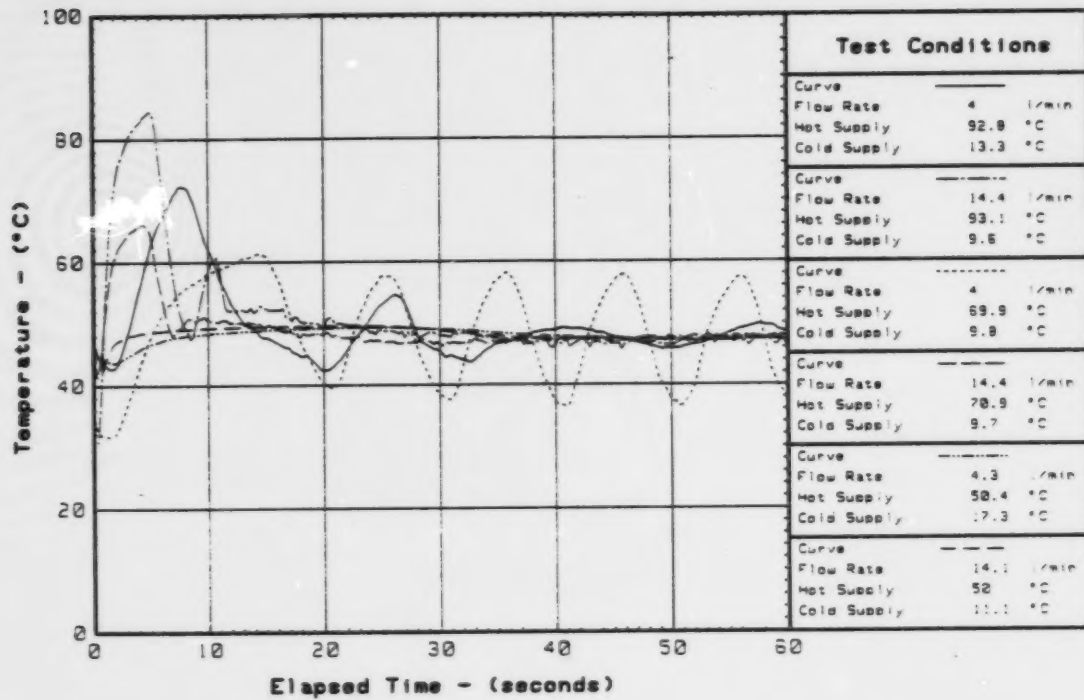
In the hot soak tests reported above, the peak delivery temperatures were higher and generally the lengths of time that the delivery temperatures were above the critical temperature were greater for the 14 l/min flow rate tests than for the 4 l/min flow rate tests.

Performance results for the Sparco Aquamix tempering valve operated from the cold soak starting condition, are shown in Figures 7c and 7d. This valve showed somewhat slower response in the cold soak tests than in the corresponding hot soak tests with both the 49 and 60°C setpoints. While the potential for scalding exists at both setpoints, it is much greater for the 60°C setpoint. The cold soak tests also confirmed that in general the 14 l/min test condition displayed a greater potential for scalding than did the 4 l/min test condition.

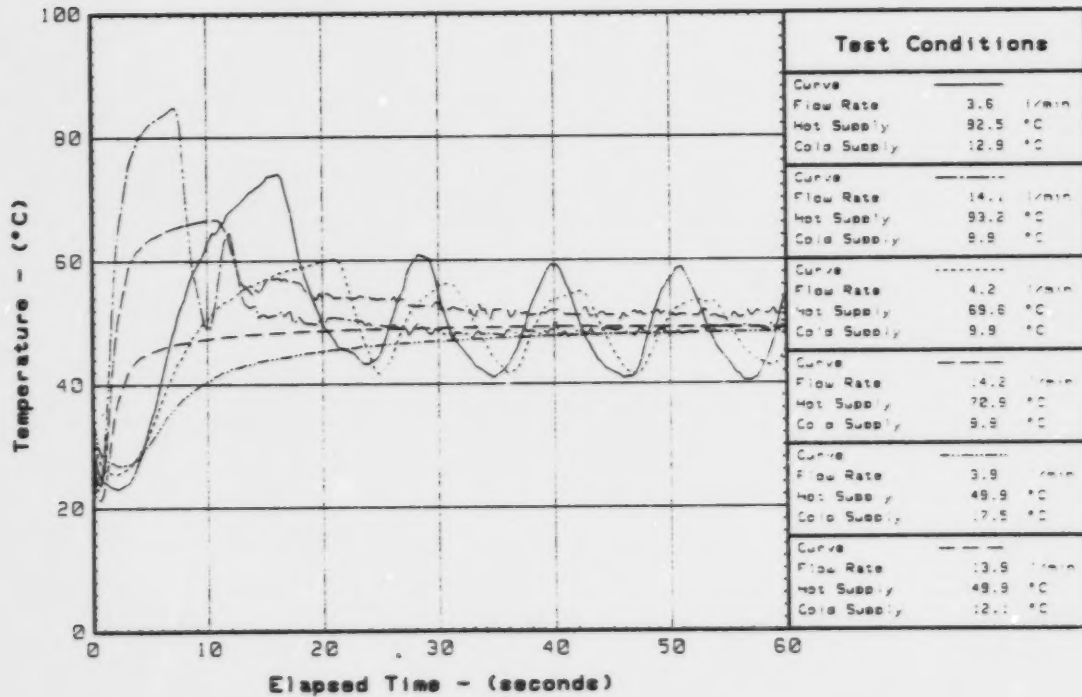
In summary, this valve displayed only limited potential for scalding at the 49°C setpoint when operated from the hot soak starting condition with hot water supply temperatures of 71 or 93°C at the 14 l/min flow rate. The cold soak starting condition significantly increased the potential for scalding and the 60°C setpoint temperature resulted in a considerable potential for scalding under most of the 71 and 93°C hot water supply temperature tests. A small amount of unwanted tempering occurred when 49°C water was supplied to the valve especially at the 4 l/min flow rate. This valve performed better from the hot soak starting condition at both setpoints.

4.2.5 Amot CMA

The Amot CMA is a moderately expensive tempering valve which is described by the manufacturer as being suitable for domestic hot water temperature limit control applications. It was the only non-adjustable valve in the group and was purchased with a 120°F (49°C) setpoint. Figure 8a shows the measured delivery temperatures for this valve when it was operated from the hot soak starting condition. The results of the tests done with a 93°C hot water supply, at both 4 and 14 l/min flow rates and the 71°C supply, 14 l/min test show that the delivery water was above the critical temperature for considerable periods of time. This indicates that scalding could occur. While the 71°C, 4 l/min test did not produce a potential scalding condition the valve displayed a cyclic variation in delivery temperature of about 20°C, with a period of about 10 seconds. This behaviour was judged to be unacceptable in the domestic application. The 93°C supply, 4 l/min test results show similar but less pronounced cyclic behaviour. The tests using a 49°C hot water

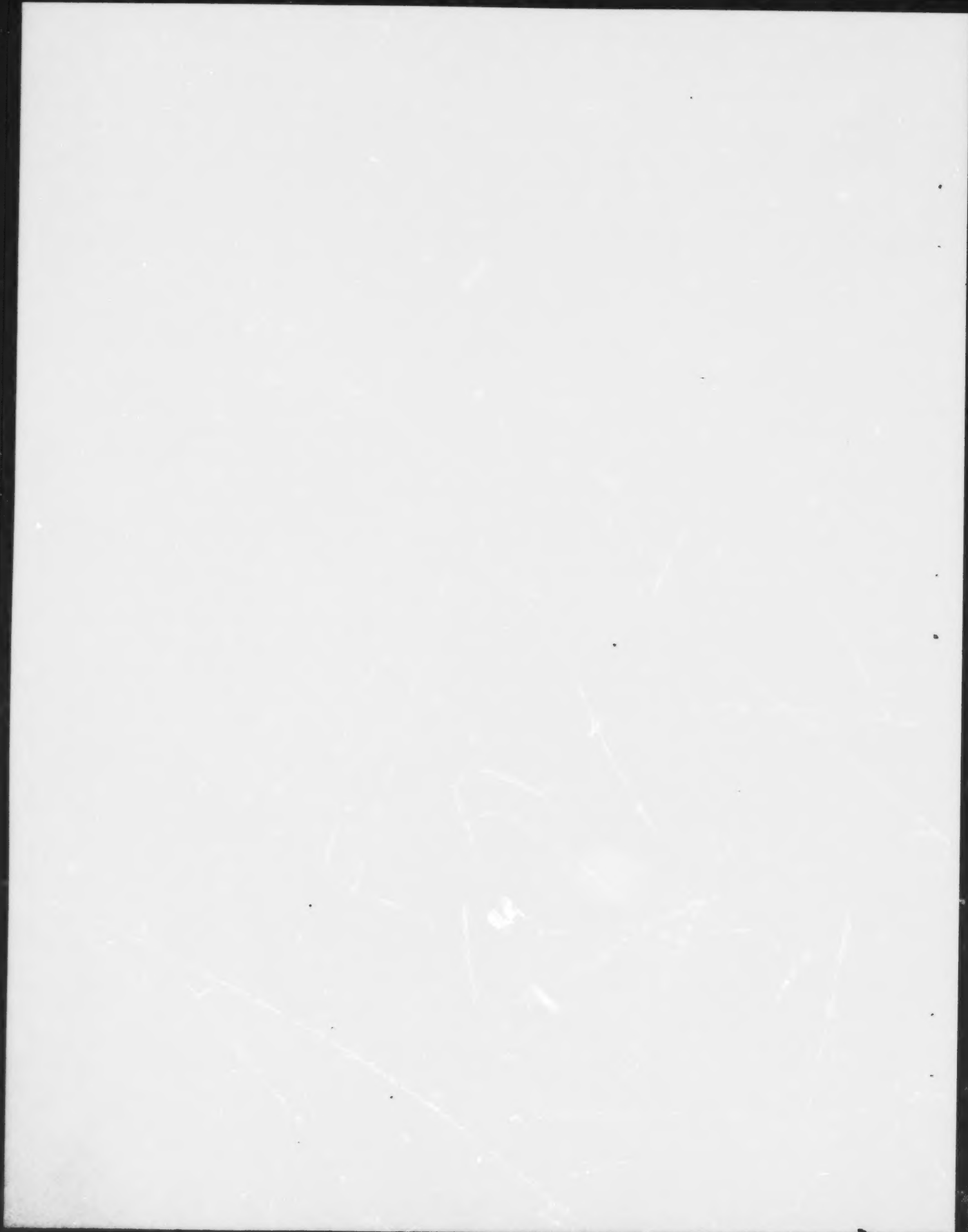


(a) Setpoint Temperature 49°C, Hot Soak



(c) Setpoint Temperature 49°C, Cold Soak

Figure 8: Measured Delivery Temperatures: Amot CMA



supply temperature posed no safety concerns, but showed that unwanted tempering was not a problem under these conditions.

In the hot soak tests report above, the peak delivery temperatures were higher and the lengths of time that the delivery temperatures were above the critical temperature were greater for the 14 l/min flow rate tests than for the 4 l/min flow rate tests. Since the valve could not be adjusted to a 60°C setpoint temperature, there is no Figure 8b.

Performance results for the Amot CMA tempering valve operated from the cold soak starting condition, are shown in Figure 8c. For this valve the cold soak tests showed considerably slower response than the corresponding hot soak tests. The cyclic variation in delivery temperature at the 4 l/min flow rate appeared to be slightly reduced for the 71°C temperature and significantly increased at the 93°C temperature. The cold soak tests also confirmed that, in general, the 14 l/min test condition displayed a greater potential for scalding than did the 4 l/min test condition.

In summary, this valve displayed considerable potential for scalding (at the fixed 49°C setpoint temperature) with 4 and 14 l/min flow rates when tested with a hot water supply of 93°C and for the 14 l/min flow rate with a 71°C supply temperature.

Unwanted tempering was not apparent, but unacceptable cyclic variation in delivery water temperature occurred at the 4 l/min flow rate. The performance of this valve was slightly better when operated from the hot soak starting condition.

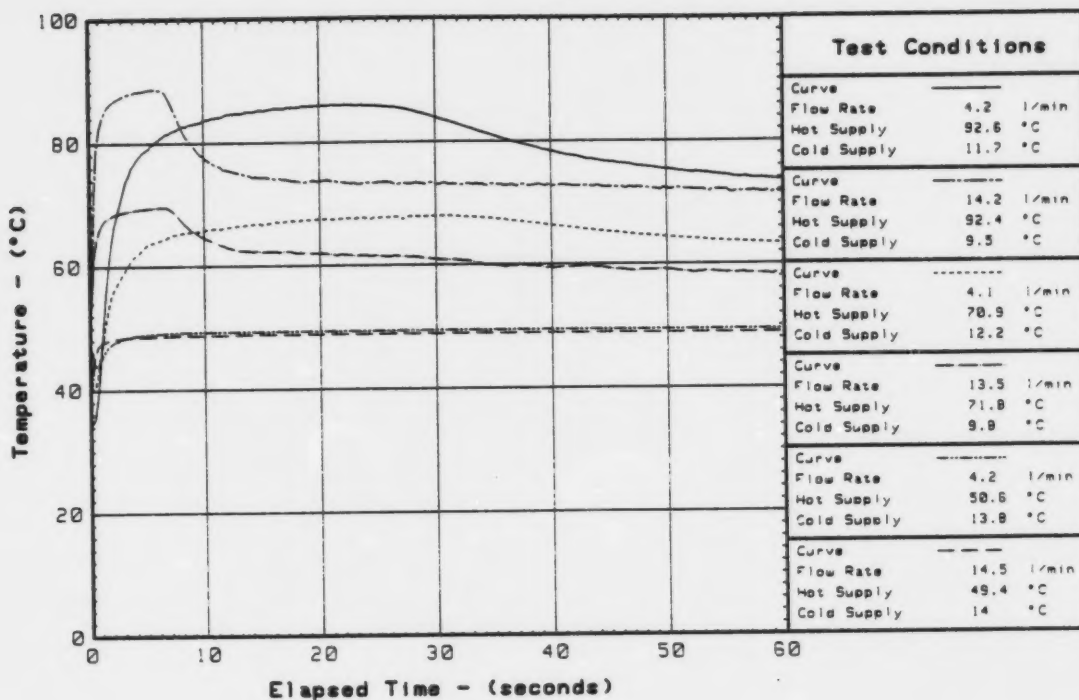
4.2.6 H & H Precision Products V220

H & H Precision Products V220 is a moderately expensive tempering valve which was imported from the United States. All of the tests performed on this valve (results shown in Figures 9a, b, c and d) with 93 and 71°C hot water, at both 49 and 60°C setpoints and 4 and 14 l/min flow rates, produced delivery water at temperatures above the critical temperature for considerable periods of time. Under all of these test conditions scalding could occur. The tests using a 49°C hot supply temperature posed no safety concerns, but showed that a small amount of unwanted tempering occurred for both the hot soak and cold soak, 60°C setpoint tests at the 14 l/min flow rate.

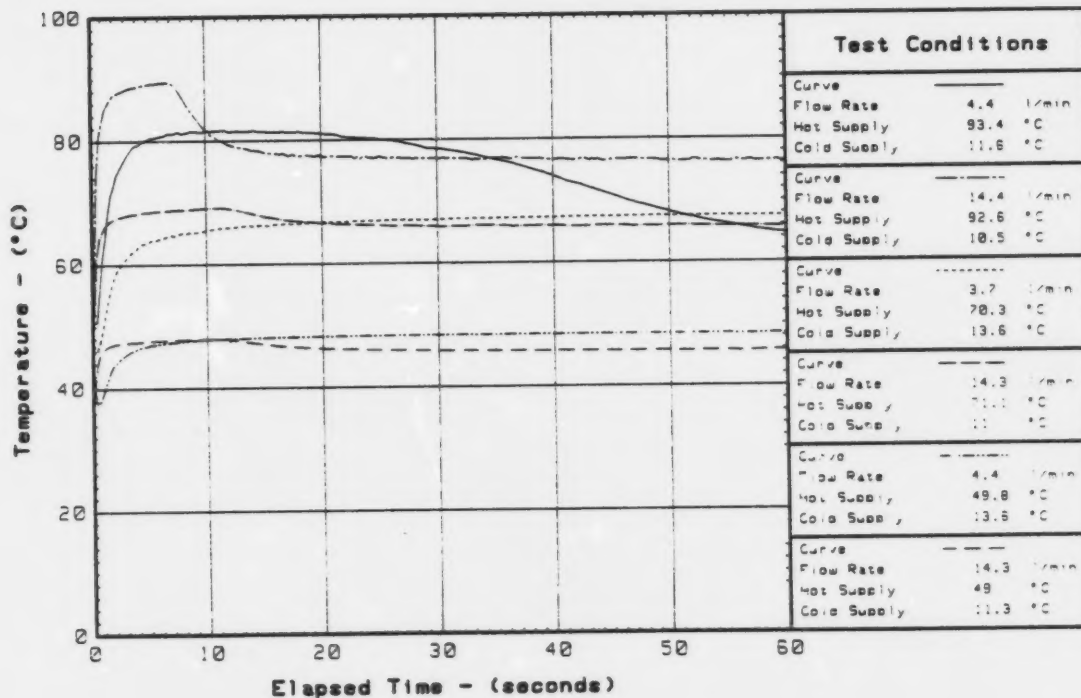
Generally, the peak delivery temperature is higher and the length of time spent above the critical temperature is greater for the 60°C setpoint than for the 49°C setpoint, suggesting an increased risk of scalding is associated with the higher setpoint. When tested at the 14 l/min flow rate with a 49°C hot water supply, this valve displayed a small amount (~2°C) of unwanted tempering.

In the tests reported above, the peak delivery temperatures were generally higher for the 14 l/min flow rate tests than for the 4 l/min flow rate tests. The delivery temperatures were generally slightly lower for the cold soak tests than for the hot soak tests.

In summary, this valve displayed considerable potential for scalding at 49 and 60°C setpoint temperatures, with 4 and 14 l/min flow rates when supplied with hot water at 71 or 93°C. A small amount of unwanted tempering occurred when 49°C water was supplied and the valve was preset to a 60°C setpoint

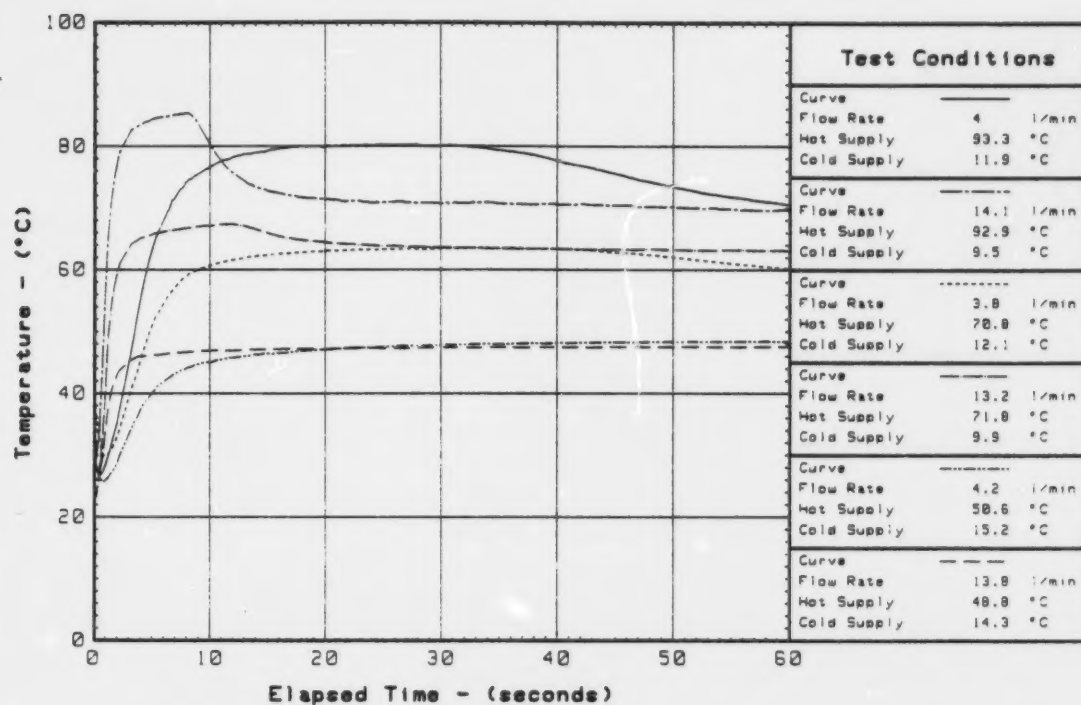


(a) Setpoint Temperature 49°C, Hot Soak

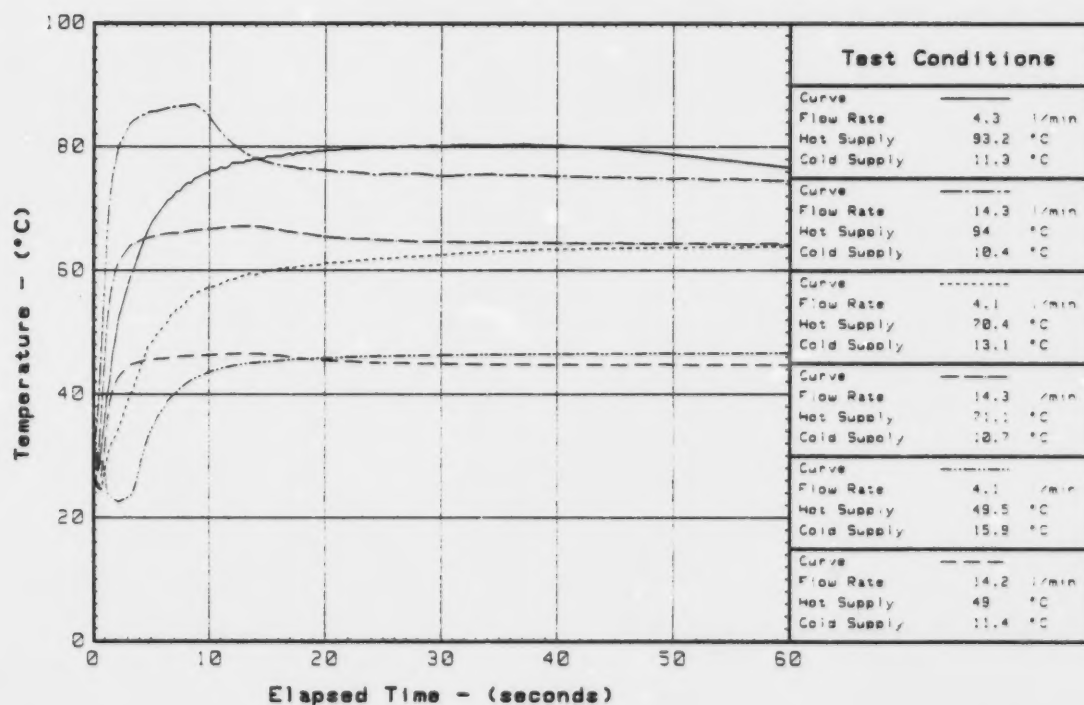


(b) Setpoint Temperature 60°C, Hot Soak

Figure 9: Measured Delivery Temperatures: H & H Precision Products V220



(c) Setpoint Temperature 49°C, Cold Soak



(d) Setpoint Temperature 60°C, Cold Soak

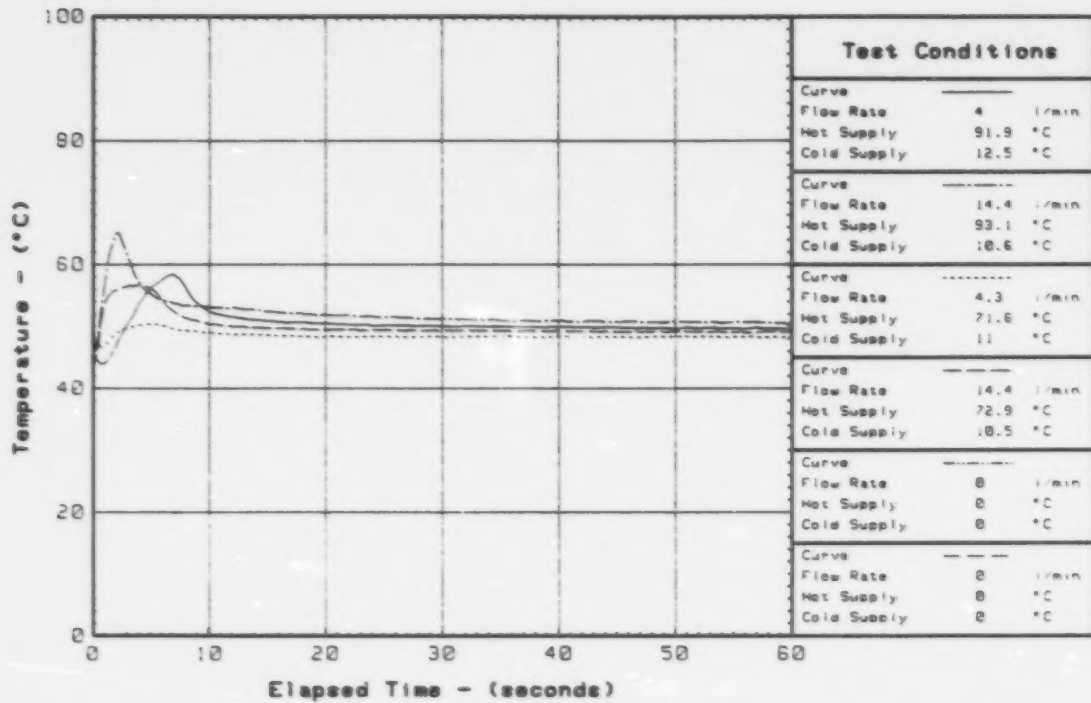
Figure 9: Measured Delivery Temperatures: H & H Precision Products V220 (Cont'd)

temperature and operated at the 14 l/min flow rate. The cold soak starting condition is preferred for this valve.

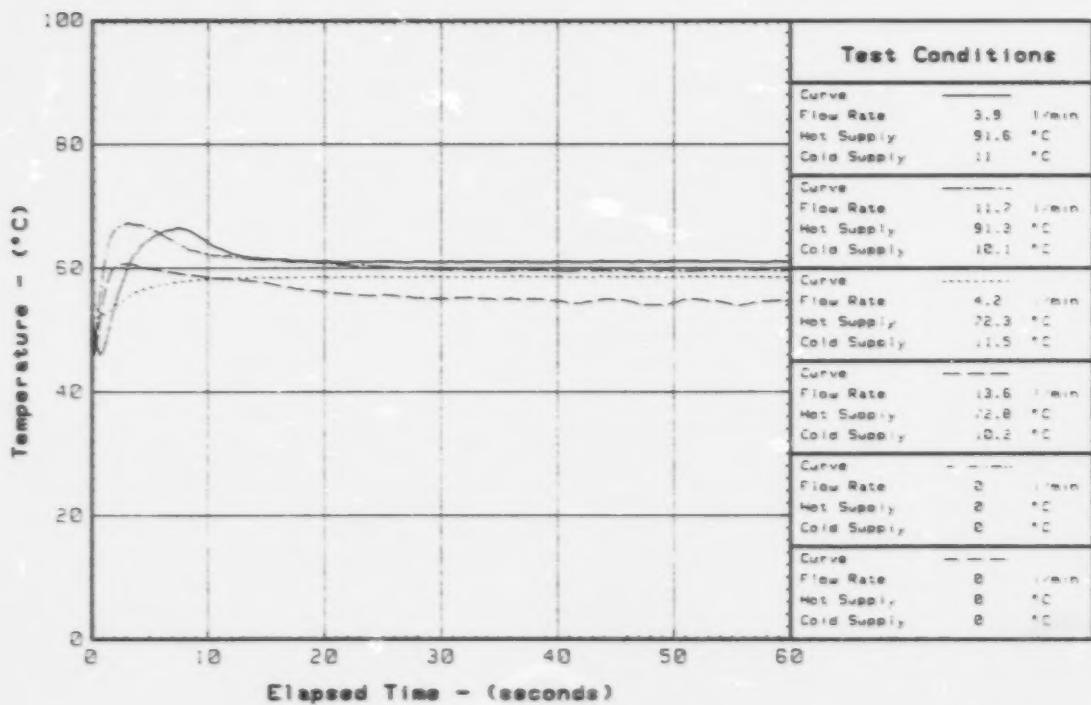
4.2.7 MCC Powers Hydroguard 420

The MCC Powers Hydroguard 420 is an expensive tempering valve which is sometimes specified for use in institutional service hot water systems. Figure 10a shows the measured delivery temperatures for this valve when it was operated from the hot soak starting condition and adjusted for a 49°C setpoint temperature. The test done with a 93°C hot water supply, and the 14 l/min flow rate produced a delivery water temperature that peaked at about 65°C and stayed above 60°C for about 2.0 seconds. Under this test condition scalding might occur. None of the other 49°C setpoint, hot soak tests produced delivery water temperatures reaching the critical temperature, implying no danger of scalding in these tests. Tests using a nominal 49°C hot supply temperature were not performed on this valve as it was not intended to operate with hot water supply temperatures less than 17°C above the setpoint temperature. An optional kit is available from the manufacturer that allows the hot water supply temperature to be as little as 1°C above the setpoint.

The measured performance of the same valve, again operated from the hot soak starting condition, but preset to a 60°C setpoint temperature, is shown in Figure 10b. Generally the peak delivery temperature was higher and the length of time spent above the critical temperature was greater than for the 49°C setpoint, suggesting an increased risk of scalding is associated with the higher setpoint. When tested at the 14 l/min flow rate with 71°C hot supply water this valve displayed a moderate amount (~5°C) of unwanted tempering.

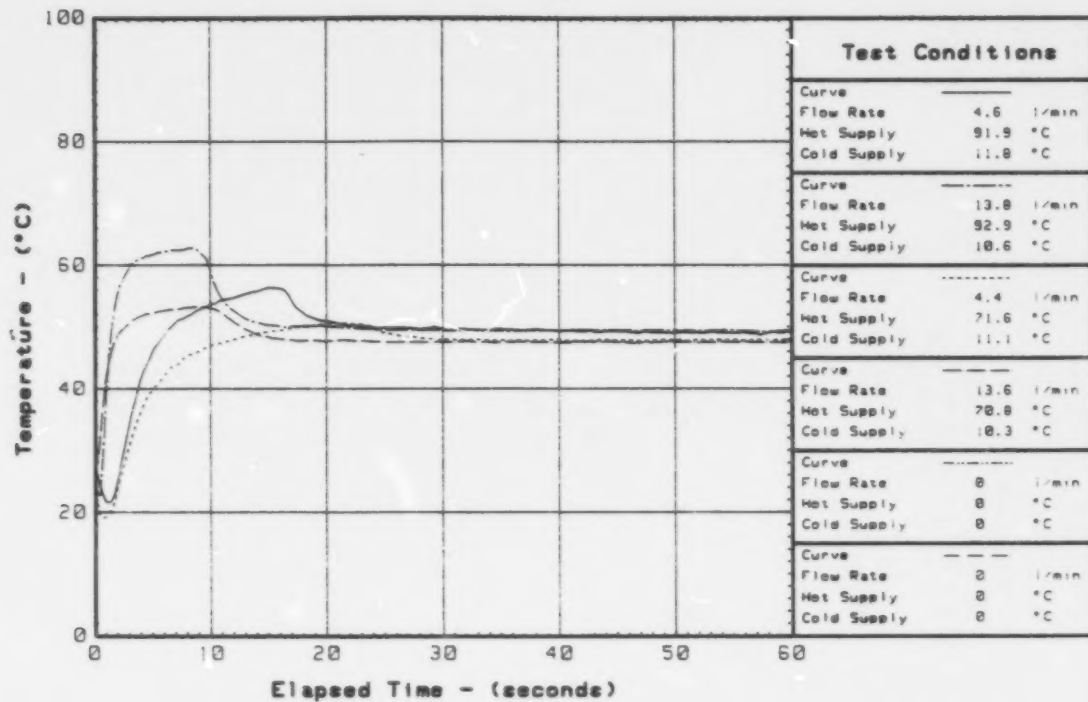


(a) Setpoint Temperature 49°C, Hot Soak

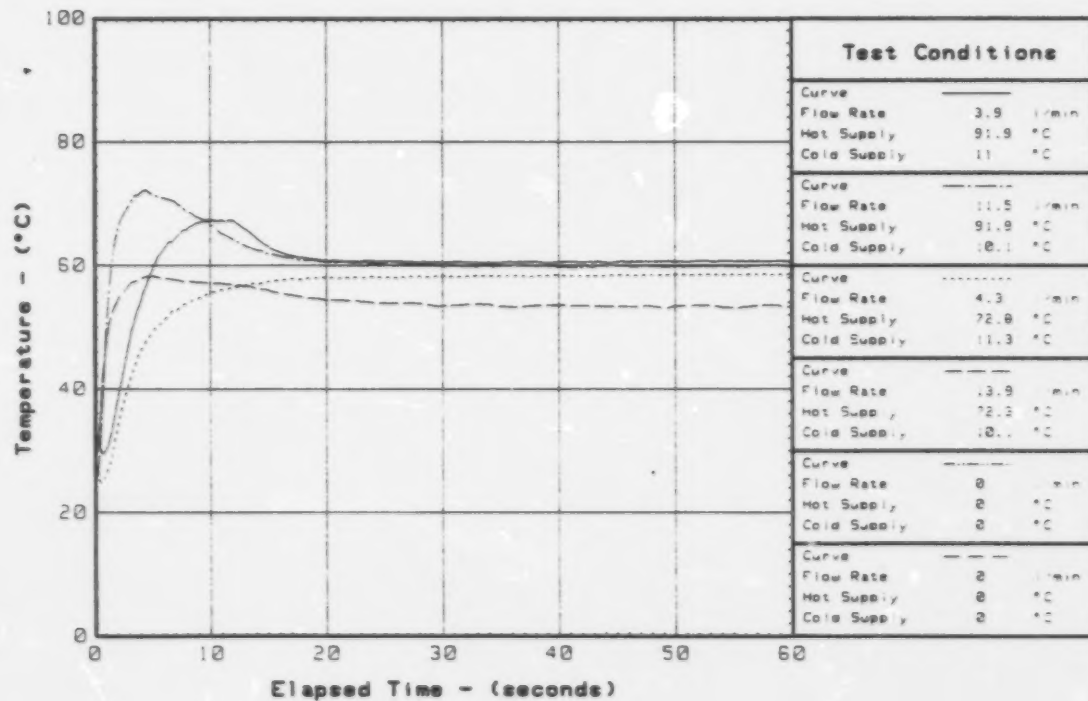


(b) Setpoint Temperature 60°C, Hot Soak

Figure 10: Measured Delivery Temperatures: MCC Powers Hydroguard 420

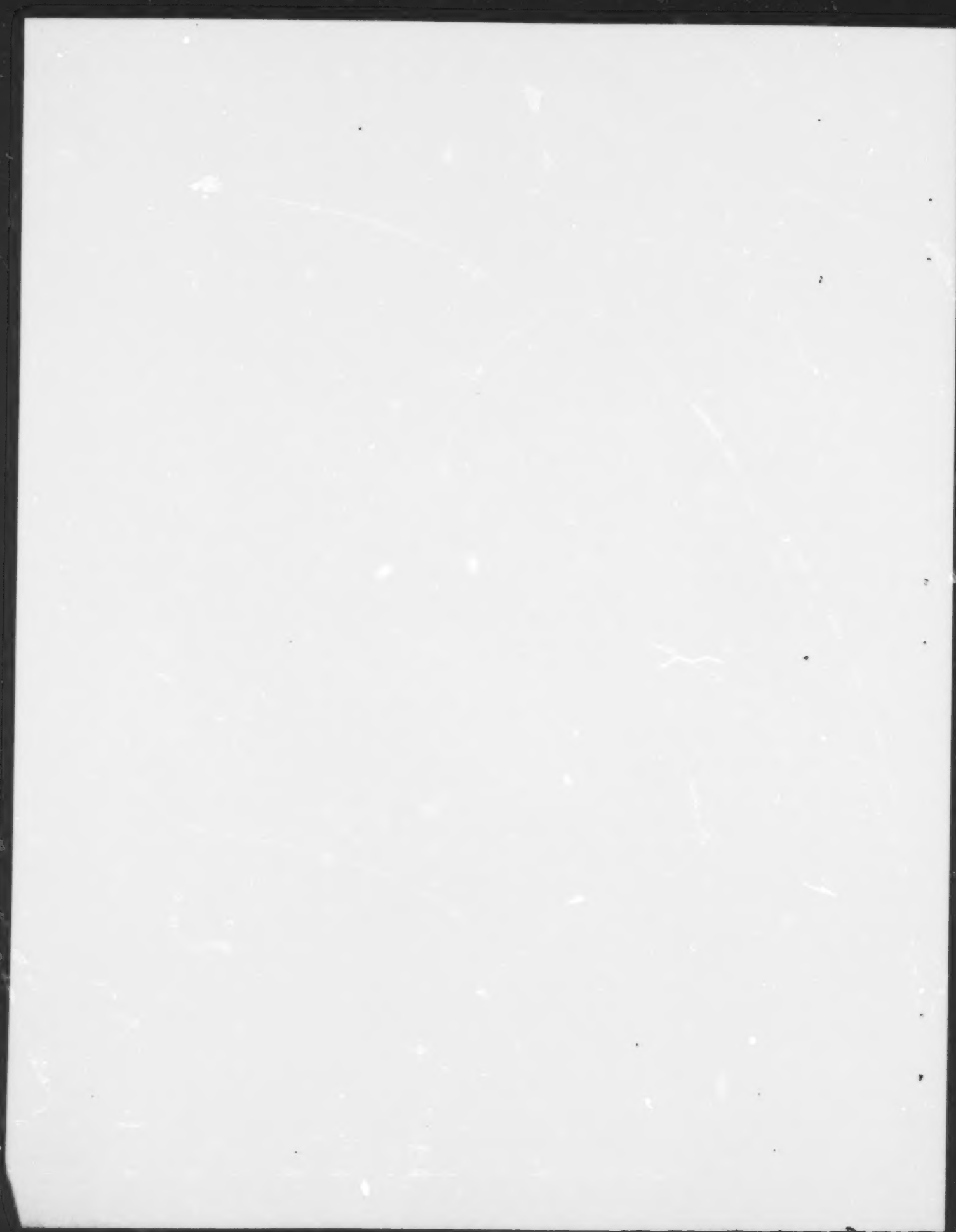


(c) Setpoint Temperature 49°C, Cold Soak



(d) Setpoint Temperature 60°C, Cold Soak

Figure 10: Measured Delivery Temperatures: MCC Powers Hydroguard 420 (Cont'd)



In the hot soak tests reported above, the peak delivery temperatures were higher for the 14 l/min flow rate tests than for the 4 l/min flow rate tests.

Performance results for the MCC Powers tempering valve operated from the cold soak starting condition, are shown in Figures 10c and 10d. For this valve the cold soak tests with the 49°C setpoint, shown in Figure 10c, showed significantly slower response than the corresponding hot soak tests shown in Figure 10a. Comparison of the hot and cold soak test results for the 60°C setpoint, Figures 10b and 10d, supported this trend. While the potential for scalding exists at both setpoints, it is much greater for the 60°C setpoint. The cold soak tests also confirmed that in general the 14 l/min test condition displayed a greater potential for scalding than did the 4 l/min test condition.

In summary, this valve displayed only limited potential for scalding at the 49°C setpoint temperature when operated from the hot soak starting condition. This occurred at the 14 l/min flow rate when supplied with hot water at 93°C. The cold soak starting condition probably did not significantly change the potential for scalding at the 49°C setpoint. The 60°C setpoint did show significant potential for scalding with the 93°C hot water supply temperature. A moderate amount of unwanted tempering occurred when the 71°C water was supplied and the valve was preset for a 60°C setpoint temperature and operated at the 14 l/min flow rate. This valve performed best when operated from the hot soak starting condition.

4.3 Discussion of Tempering Valve Test Results

Tables 3a and 3b summarize the scald protection performance of the valves tested, for the 49°C and the 60°C setpoints respectively. The performance of these valves falls within the range "completely unacceptable" to "acceptable under some circumstances". The valve with the best test performance, the MCC Powers Hydroguard 420, is too expensive (\$459) to be added to the cost of a single-family SDHW system but it would probably be appropriate for multi-family sized systems.

The next to best performing valve, the Sparco Aquamix AM100, was significantly less expensive (\$64) but, like the MCC Powers valve, did produce delivery water temperatures above 60°C for short periods under some conditions. Since this valve performs best when operated from the hot soak starting condition it is assumed that it would be installed in a location that produces this condition. Installed in this way, and preset for a 49°C setpoint temperature, the Aquamix still produced brief (< 3s) temperature excursions above the 60°C critical temperature and associated small volumes of very hot water (< 0.75 l) immediately after initiation of flow at 14 l/min, for both 71 and 93°C hot water supply. This suggests that such valves are best used in conjunction with some other means of limiting the delivery temperature. A small storage volume located downstream of the valve might be sufficient for this purpose.

While the 49°C valve setpoint temperature generally resulted in safer delivery temperatures than the higher setpoint, it is significantly lower than the commonly used 60°C auxiliary tank setting. A delivery temperature of 49°C (120°F) should be more than adequate for all sink/shower loads but higher

temperature water, at the dishwasher and clothes washer, may be desirable and obtained via a separate untempered supply line for these appliances. Generally the tempering valves tested also worked at the higher 60°C setpoint temperature but with substantially greater risk of scalding.

Two cautions must be identified at this point. The tempering valves purchased for this study were tested in the new, as received, condition. It is possible, and, depending on the operating conditions, likely that the performance of some of the valves will deteriorate with use. The subject of accelerated aging of tempering valves, that would facilitate their testing in an "aged" condition, is addressed in Section 6 of this report.

The second concern relates to the suggested installation location to achieve the desired hot soak or cold soak starting condition for a particular valve. The indicated preference for either starting condition in Section 4 was based strictly on the test results for the valves in the new condition. Differences in scaling and corrosion rates that may be associated with the two installation locations could possibly outweigh the "new" performance preferences and may even be different for the different water types found in various locations across the country.

Table 3a
Tempering Valve Test Summary
49°C Setpoint

Starting Condition	Hot Soak						Cold Soak					
Hot Supply Temp. (°C)	93		71		49		93		71		49	
Flow Rate (L/min)	4	14	4	14	4	14	4	14	4	14	4	14
Watts 70A	X	X	X	X			X	X	X	X		
Cash Acme TMA-3		X	X	X				X				
Sparco TV120	X	X		X			NA ¹	NA ¹	1	1	1	1
Sparco Aquamix		X		*			*	X		X		
Amot CMA	X	X		X			X	X		X		
H & H V220-1	X	X	X	X			X	X	X	X		
MCC Powers		X			NA	NA		X			NA	NA

X = occurrence of potential scalding condition

* = borderline potential scalding condition

NA = data not available, no test performed

Notes: ¹ This valve is believed to have failed

Table 3b
Tempering Valve Test Summary
60°C Setpoint

Starting Condition	Hot Soak						Cold Soak					
Hot Supply Temp. (°C)	93		71		49		93		71		49	
Flow Rate (l/min)	4	14	4	14	4	14	4	14	4	14	4	14
Watts 70A	X	X	X	X			X	X	X	X		
Cash Acme TMA-3	X	X	X	X			X	X	X	X		
Sparco TV120	X	X	X	X			X ¹	X ¹	1	1	1	1
Sparco Aquamix		X		X			X	X	X	X		
Amot CMA					Not adjustable to 60°C							
H & H V220-1	X	X	X	X			X	X	X	X		
MCC Powers	X	X			NA	NA	X	X			NA	NA

X = occurrence of potential scalding condition

NA = data not available, no test performed

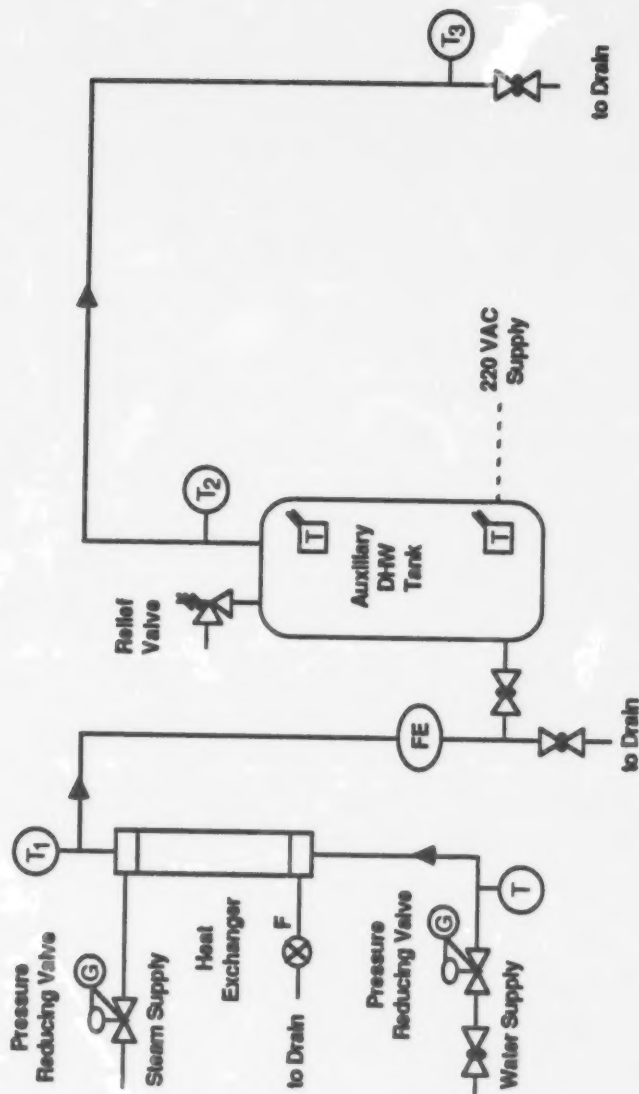
Notes: ¹ This valve is believed to have failed

5. AUXILIARY TANK AS A BUFFER TESTING

While it is reasonable to expect that very hot water (from a solar storage tank) will be cooled to some degree by flowing through an auxiliary tank full of water at a lower temperature, it is not clear how much the temperature will be reduced. A short series of tests was performed to experimentally determine the outlet temperature of an auxiliary tank when it is supplied with water at temperatures above its setpoint temperature at different flow rates.

5.1. Method

The tests on the auxiliary tank as a buffer were performed using the apparatus shown schematically in Figure 11. Power to the GSW Model 5E520-123 180 litre electric DHW tank with 60°C setpoint was turned on the day before the test was to be performed allowing the tank temperatures to reach steady state. Before the start of the test hot water was drawn from the heat exchanger and dumped to drain so that adjustments to achieve the desired flow rate and supply temperatures could be made. At the start of the test the bypass valve to drain was closed and the valve to the tank opened, allowing the draw to be supplied from the tank, which in turn was supplied by essentially constant temperature hot water. The temperature of water entering the auxiliary tank was measured with a conventional thermocouple while the temperature of water leaving the auxiliary tank and leaving the 5.7m discharge line was measured with fast response thermocouples. A Hewlett Packard Data Acquisition System scanned and recorded the temperature and flow data every 2.5 seconds. The temperature data were plotted on the screen for review following each 60 minute test. Tests were



NOTE: T₁ - Hot Supply Temperature
 T₂ - Tank Outlet Temperature
 T₃ - Discharge Temperature

Figure 11. Schematic of Buffering Capacity Test

performed with nominal 71 and 93°C supply temperatures with nominal flow rates of 4 and 14 L/min. The four resulting test conditions were each applied to two electric tank operating configurations: (1) the conventional two element operation; and (2) the top element only operational (for an expected increase in buffering capacity).

5.2. Test Results

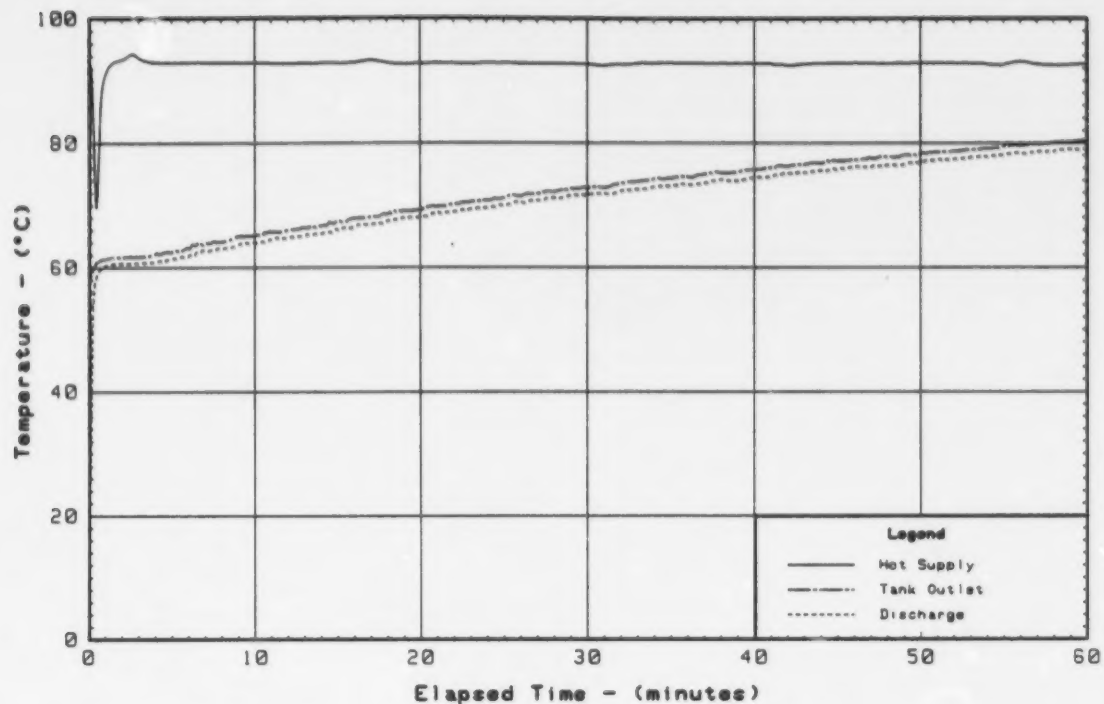
The auxiliary tank test results are briefly summarized in Table 4 and are presented in more detail below. Results for the test tank with both heating elements operational will be considered first since this is the most commonly used configuration.

The 4 L/min, 93°C inlet temperature test result is shown in Figure 12a. The auxiliary tank outlet temperatures stayed constant at the tank setpoint temperature for the first three to four minutes or about 15 L of draw. It then increased gradually towards the tank supply temperature, reaching 80°C after 60 minutes (240 L) of draw. The temperature of water leaving the 5.7m supply pipe remained approximately 1°C lower than that leaving the tank throughout the test.

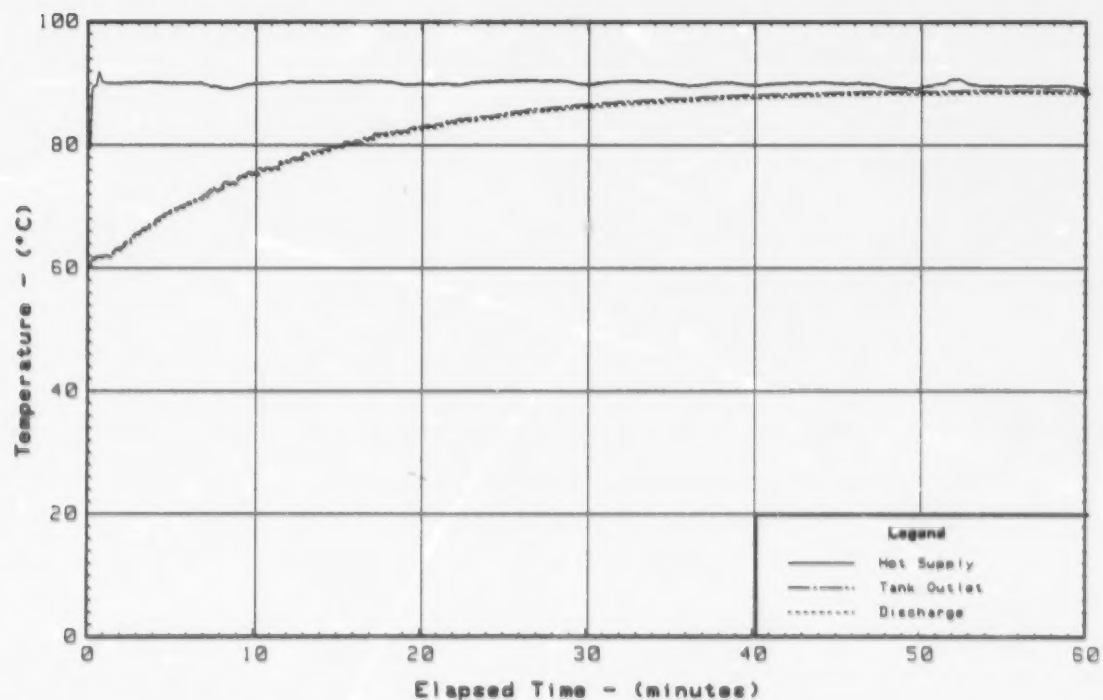
The result for the 14 L/min flow rate test at the same temperature appears in Figure 12b. It shows that the tank outlet temperature remained at setpoint for about 1.5 minutes or 20 L of draw. It then increased more rapidly towards the hot supply temperature reaching 80°C after 15 minutes (210 L) of draw, and 89°C after 60 minutes (840 L) of draw. The discharge water temperature remained less than 0.5°C lower than the tank outlet temperature throughout the test.

Table 4
Buffering Test Summary

Test Supply	Two Elements Operational				One Element Operational			
	93°C Supply		71°C Supply		93°C Supply		71°C Supply	
	4ℓ/min	14ℓ/min	4ℓ/min	14ℓ/min	4ℓ/min	14ℓ/min	4ℓ/min	14ℓ/min
Time until Setpoint Exceeded (min)	3.5	1.5	9	2.5	25	8	33	15
Maximum Test Outlet Temperature (°C)	50	89	67	70	75	89	66	70
Minimum Test Outlet Temperature (°C)	Set-point	Set-point	Set-point	Set-point	Set-point-12	Set-point-12	Set-point-10	Set-point-18
Supply Pipe Temperature Reduction (°C)	1.5	0.5	1.5	0.5	1.5	0.5	1.5	0.5

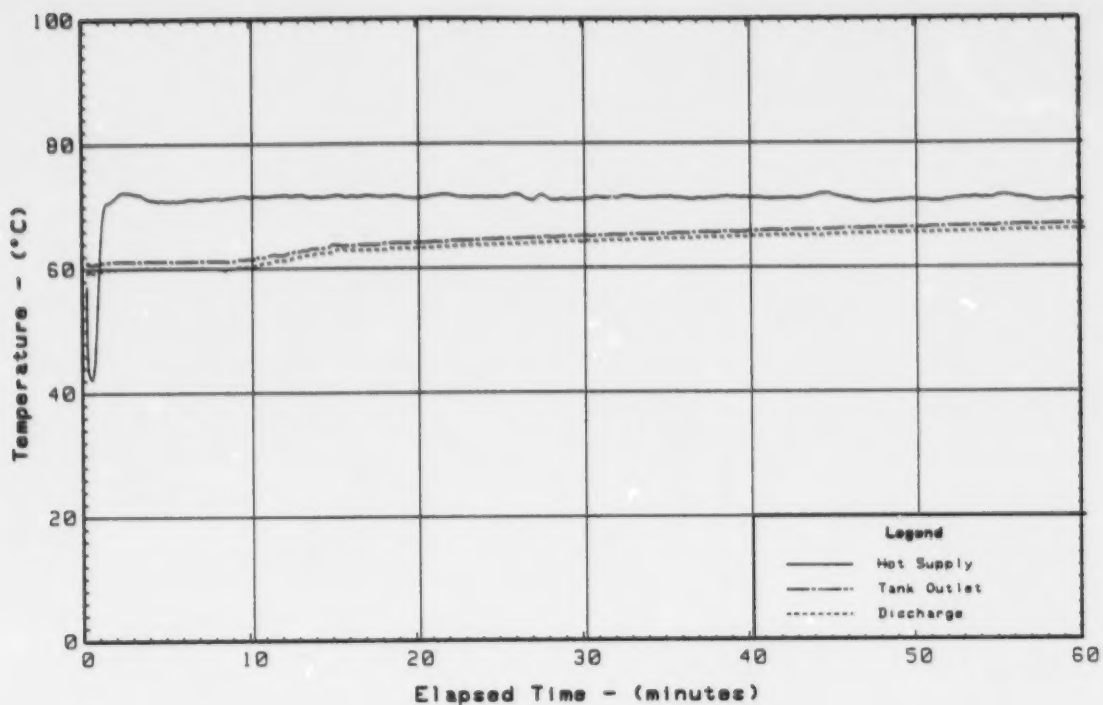


(a) Flow 4 l/min - Supply Temperature 93 °C

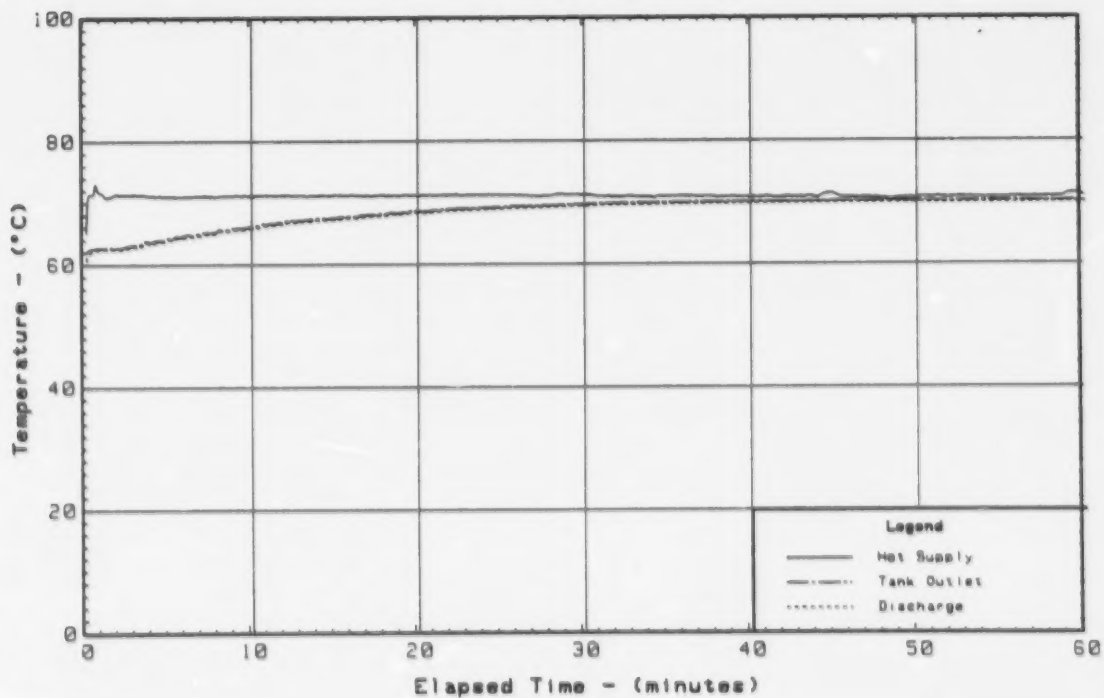


(b) Flow 14 l/min - Supply Temperature 93 °C

Figure 12: Buffering Capacity Tests - Both Elements Operational



(c) Flow 4 l/min - Supply Temperature 71 °C



(d) Flow 14 l/min - Supply Temperature 71 °C

Figure 12: Buffering Capacity Tests - Both Elements Operational (Cont'd)

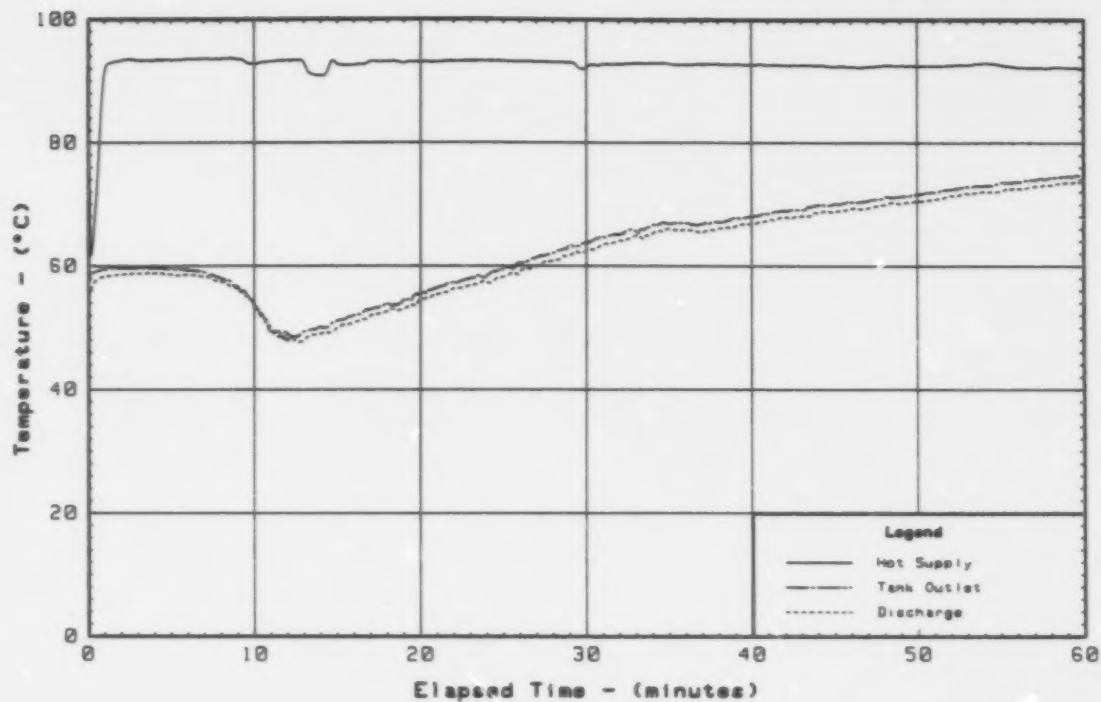
While severe scalding could result from water leaving the auxiliary tank during the above tests, the tank outlet and discharge temperatures did change gradually.

The 4 L/min, 71°C supply temperature test result is shown in Figure 12c. The outlet temperature followed essentially the same pattern as in the 4 L/min, 93°C test, except that it stayed longer at the tank setpoint (9 minutes or 36 L) and did not rise as quickly (67°C after 60 minutes of draw). Similarly the 14 L/min flow rate, 71°C test result shown in Figure 12d closely follows the pattern for the 93°C test shown in Figure 12b. In this case the maximum temperature of 70°C was reached after approximately 35 minutes of draw. The discharge temperature stayed about 1°C and 0.5°C lower than the tank outlet temperature for the low and high flow rate tests respectively, as it did in the high temperature tests.

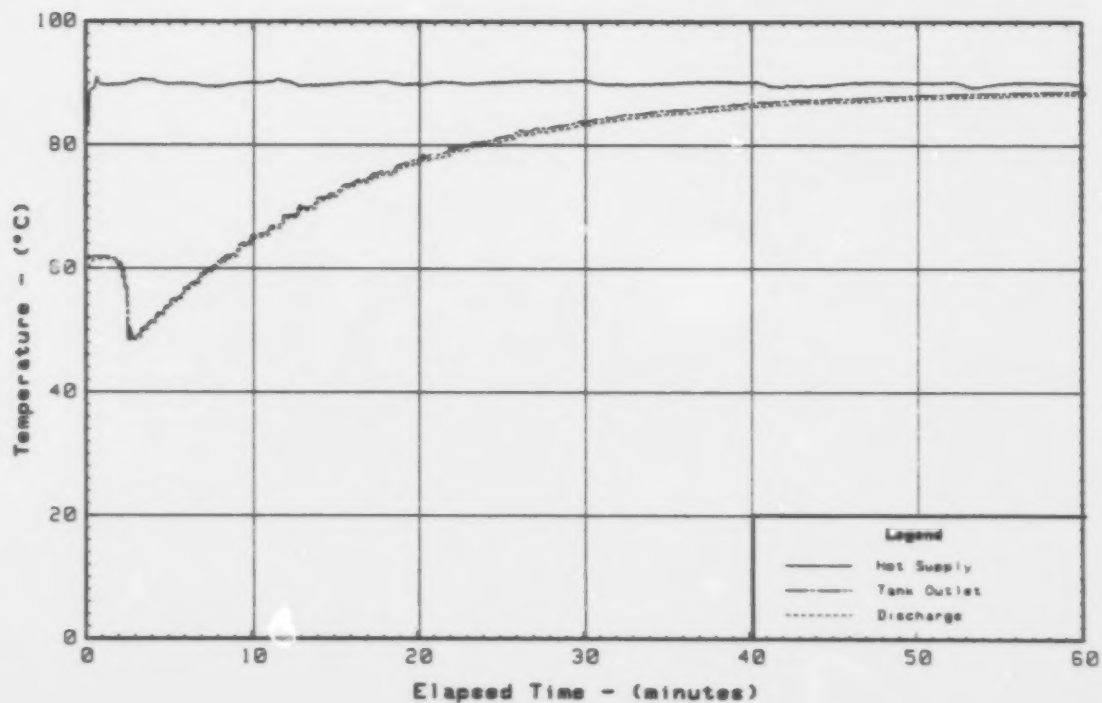
Results of tests performed on the auxiliary tank with only the top element operational are presented in Figure 13.

The 4 L/min, 93°C inlet temperature test result, Figure 13a, shows that the outlet temperature stayed at or below the tank setpoint for 15 minutes (or 100 L of draw) and reached 75°C at the end of the 60 minute test. This temperature dropped as low as 48°C approximately 12 minutes into this test. The discharge temperature remained about 1°C lower than the tank outlet temperature through most of the test.

The result for the 14 L/min, 93°C test, Figure 13b, shows that the tank outlet temperature remained equal to or less than the tank setpoint for approximately 8 minutes (or 110 L of draw)

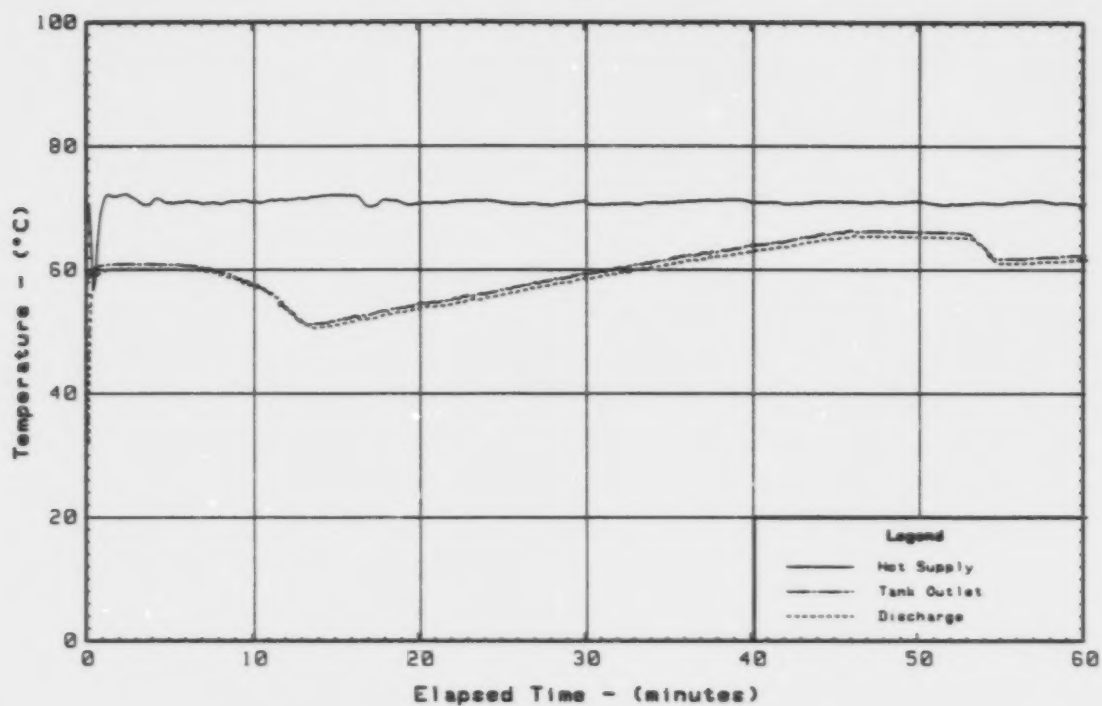


(a) Flow 4 l/min - Supply Temperature 93 °C

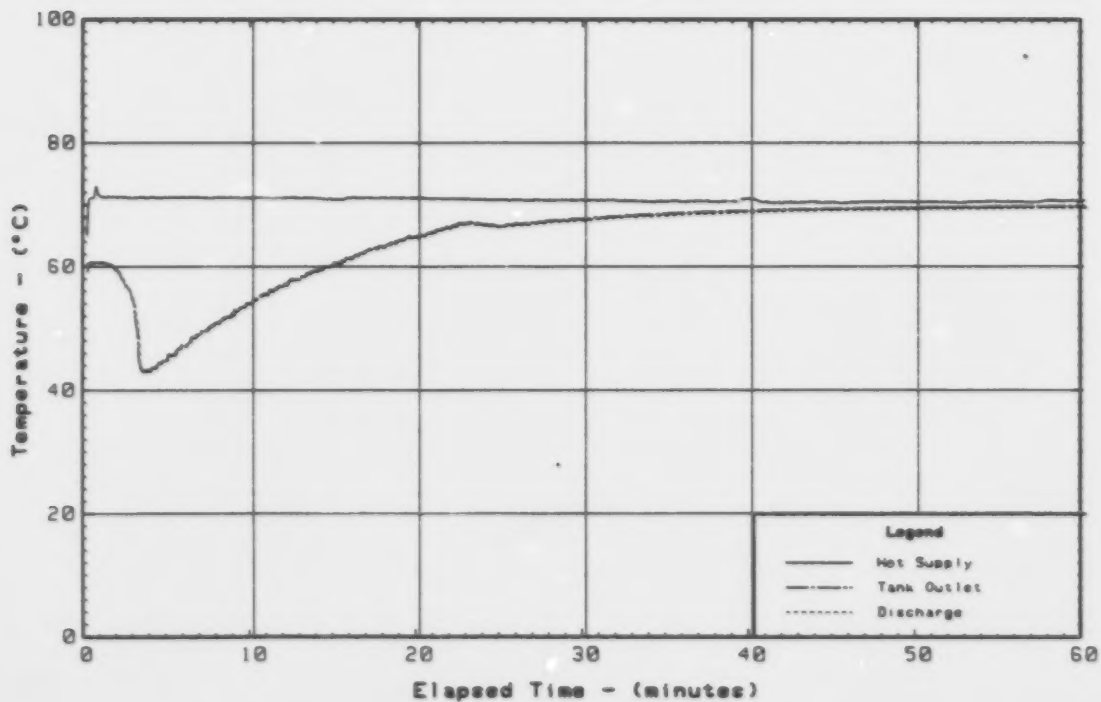


(b) Flow 14 l/min - Supply Temperature 93 °C

Figure 13: Buffering Capacity Tests - One Element Operational



(c) Flow 4 l/min - Supply Temperature 71 °C



(d) Flow 14 l/min - Supply Temperature 71 °C

Figure 13: Buffering Capacity Tests - One Element Operational (Cont'd)

and reached 89°C at the end of the 60 minute test. This temperature dropped about 12°C below the tank setpoint about 2.5 minutes into this test. The discharge temperature remained within 0.5°C of the tank outlet temperature throughout the test.

The result for the 4 l/min 71°C test is shown in Figure 13c. The tank outlet temperature remained at or below the tank setpoint for approximately 30 minutes (130 l of draw) and reached a peak of 66°C about 46 minutes into the test and then dropped down to within 2°C of the setpoint. This temperature dropped as much as 10°C below the tank setpoint about 13 minutes into the test.

The result for the 14 l/min 71°C test, Figure 13d, shows that the tank outlet temperature followed essentially the same pattern as in the 14l/min, 93°C test except that it dropped to a lower temperature (43°C) near the beginning of the test (about 3.5 minutes) and stayed below the tank setpoint temperature longer (about 15 minutes or 210 l of draw). It reached 70°C at the end of the 60 minute test, increasing very little over the second half of the test. As in the high temperature tests, the discharge temperature stayed about 1°C and 0.5°C lower than the tank outlet temperature for the low and high flow rate tests respectively.

5.3 Discussion

Most SDHW systems sold in Canada are of the preheat system type. These are two tank systems in which the solar storage tank feeds water to a conventional hot water tank, which in turn supplies the load. While the two tank configuration may not be ideal from a

thermodynamic standpoint, it does have the advantage that the potentially dangerous hot water in the solar storage tank must pass through the auxiliary tank before reaching the house supply plumbing. The tests and results described above should provide an indication of roughly how much the auxiliary tank might be expected to reduce the temperature of water supplied to the user.

Water in this tank will generally be at the setpoint temperature and will therefore tend to reduce the temperature of hotter water that flows into it from the solar storage tank. However, as the setpoint temperature of auxiliary tanks is typically 60°C, there is essentially no capacity (in fossil fired tanks or in electrically heated tanks with both elements operational) to lower the temperature of hotter incoming water to a temperature that will not cause scalding. Another limitation arises when large amounts of very hot water are supplied from the solar storage tank. The "buffering" capacity of the auxiliary tank is used up as it becomes filled with high temperature water.

In summary, the two element auxiliary tank can reduce the likelihood of scalding hot water reaching the user, but if the setpoint is 60°C this temperature was exceeded in 1.5 to 9.0 seconds depending on the inlet water temperature and flow rate. Significant amounts of water did have to be drawn however before the tank outlet temperature closely approached the hot supply temperature, suggesting that normally the auxiliary tank will tend to cool hotter incoming water somewhat. As pointed out above, the tempering capability of an auxiliary tank cannot always be relied on since the solar system may at times fill it with dangerously hot water.

The situation is similar for electrically heated tanks with only the top element operational except that in this case:

1. Less hot water will be available to the load at times of low or moderate solar contribution (about 30 litres of hot water at the setpoint). The supply temperature therefore may drop well below setpoint after this volume of hot water has been drawn*.
2. Significantly more time elapses (8 to 25 seconds) before the setpoint temperature is exceeded when the tank is supplied with water above the setpoint.

It may be possible to define an optimum period for an operating strategy that uses both elements of an electric auxiliary in the lower solar fraction months, when the probability of encountering higher solar heated water temperatures is low, and uses only the top element in the highest solar fraction months so that the probability of having insufficient hot water is reduced.

During the course of the tank buffering capacity tests no tendency for hot water inlet water to "stream" to the outlet was observed with the GSW tank used in the tests. If it had been occurring an early sharp rise in outlet temperature would be expected. It is possible that other tank designs may produce inlet to outlet streaming under some conditions.

* This shortcoming results from the standard tank design and should be easy to avoid with a tank designed specifically for single tank systems.

6. ACCELERATED AGING

The Materials Corrosion Section examined the tempering valves, commented on scaling and/or corrosion observed and suggested an accelerated aging procedure for them.

6.1 Examination of Six Tempering Valves

During the thermal performance testing described in Section 4 of this report the total operation time of each valve was of the order of two hours. Following the experiments the valves that were purchased for test were disassembled and examined for evidence of scale or corrosion

The Amot CMA valve showed evidence of scaling and bulky white corrosion products. In addition, corrosion of the substrate was evident on some of the plated steel internal components of this valve.

The H & H Precision Products V220 valve was made of copper and copper alloys and showed little evidence of scaling or corrosion. However, there was a large crack in the largest diameter portion of the thermal element assembly.

The Watts 70A and Cash Acme TMA-3 valves appeared to be almost identical in construction and were made mainly from copper and copper alloys. Both valves showed some evidence of scaling. The Sparco TV120 valve was also made from copper and copper alloys. It showed less evidence of scaling than the Watts and Cash Acme valves. The geometry of the internal valve assembly appears better able to resist impingement corrosion than that of the four valves referenced above.

The Sparco Aquamix valve was made from nickel plated copper alloys and copper. It showed some evidence of scaling and some corrosion of the nickel plating. The geometry of the internal valve assembly appears better able to resist impingement corrosion than that of the first four valves referenced above.

6.2 Potential Problems with Valves in Operation

Three problems which may develop with these tempering valves are: (1) scaling, (2) galvanic corrosion, and (3) impingement corrosion. Any of these problems could lead to failure or malfunctioning of the valve.

Scale formation can interfere with the operation of the internal components of a valve and cause a flow restriction by reducing the cross-sectional area of the outlet and the piping from the outlet.

The scale forming tendency of water increases as the water temperature increases. The hottest water encountered in the tempering valve is that heated by the solar system; however, most of the scale that is likely to be formed from that water would form in the system component where the water heated (the collector or heat exchanger) rather than in the valve. The incoming cold water which is mixed with the hot water in the valve would still contain its scale forming salts and the potential to deposit some of these in the valve if it is heated sufficiently there.

The temperatures of the two feed waters and the desired final temperature plus the chemical composition of the two feed waters will determine whether or not the water in a particular location would be scale forming. The parameters which determine whether or

not water would be scale forming are: pH, temperature, total dissolved solids, hardness and alkalinity. The possibility of scale formation would have to be considered on a city by city basis.

Galvanic corrosion can result in the failure of components that have been weakened by the removal of material. Galvanic corrosion results from the contact of dissimilar metals in an electrolyte. In the tempering valves examined there are a variety of galvanic couples which can occur in water: galvanic corrosion requires all of the following conditions: (1) dissimilar metals, (2) a metallic contact between the metals, (3) water in contact with both metals and (4) oxygen in the water. The first three conditions are certainly met in the tempering valves in operation.

The oxygen concentration in the hot water would be much less than in the cold water supply (because of degassing with increasing temperature) but would likely be high enough for galvanic corrosion to occur. This situation is much different from a recirculating building heating system where the small amount of oxygen in the make-up water is rapidly consumed and copper-iron couples survive many years service with no evidence of galvanic corrosion having occurred. The Amot valve had aluminum plated steel rod in contact with brass in the thermal element assembly. The Cash-Acme valve also had a steel spring (zinc or cadmium plated) in contact with the brass while the Watts valve had a steel spring plated with copper in contact with brass. The Sparco TV120 valve also had a steel spring in contact with brass. The Sparco Aquamix valve had nickel plated brass in contact with copper. The nickel plating was of insufficient thickness and had corroded probably because of coupling with exposed brass.

Impingement corrosion which also weakens components by removal of material is a common problem in building water systems. It is a combination of corrosion and erosion and occurs when the water is flowing at a high velocity over a metal surface. Copper pipe suffers from impingement corrosion when the water velocity exceeds approximately 1.22 m/s. Impingement corrosion is accelerated when water temperatures exceed 57°C or in areas of turbulent flow caused by elbows, ridges, or changes in pipe diameter.

The largest diameter portions of the thermal element on the Amot and both Sparco valves are rounded. The geometry will reduce the chances of turbulent flow occurring. The area of greatest flow restriction is between the cold water inlet and the mixing area. The flow is again restricted at the mixed water outlet. Higher water velocities can be tolerated by stainless steel or nickel alloys than by copper alloys.

6.3 Suggested Aging Procedure

The effect of impingement corrosion is expected to be the most important component in artificial aging of the tempering valves. The relative importance of scaling and galvanic corrosion will depend on: (1) the scale forming tendency of the water, (2) the oxygen concentration in the water and (3) the galvanic couples in a particular valve. In Canada potable water can be either scale forming or corrosive and depending on the source of the water contain up to the solubility limit of oxygen (8 ppm @ 20°C).

In CSA Standard F379.1 M1985 a standard test day is defined in which a daily hot water load of 225 L is drawn at 10 L/min. A flow rate of 10 L/min in 1/2 inch copper tube corresponds to a

velocity of 1.69 m/s which is high enough to cause impingement corrosion in the copper tube. Since the standard day requires flow time of 22.5 minutes, 365 standard days, or one year, would need approximately 137 hours of actual running time.

The tempering valve being aged would be run at typical operating temperatures, say $T_{\text{cold}} = 10^{\circ}\text{C}$, $T_{\text{mix}} = 49^{\circ}\text{C}$, $60^{\circ}\text{C} < T_{\text{hot}} < 95^{\circ}\text{C}$ (with the vast majority of time spent at the lower end of this range).

Although artificially aging the tempering valves by operating them for 137 hours at an output of 10 l/min would adequately represent one year of impingement corrosion it would fall short of adequately representing the scaling or galvanic corrosion which would be expected to occur in one year. To produce one year's galvanic corrosion would require one year because there is no means of representatively accelerating galvanic corrosion. The best that can be achieved is to have a long enough exposure time to ensure that if galvanic corrosion is going to occur, it will be observable at the end of the artificial aging procedure.

One year's scaling could be approximated by periodically letting the system sit with no flow to allow scale to form and adhere to the valve internally without being swept away by a high fluid flow rate.

By operating the system at 10 l/min output for 15 minutes, followed by 45 minutes of no flow, the tempering valves could be aged in approximately 23 days. The 45 minute pause might be used to allow the hot water supply to be heated between flow periods, some scaling to occur and would likely extend the exposure time enough to permit galvanic corrosion to be observed.

7. DISCUSSION OF RESULTS AND REVIEW OF THE ROUTINE OVERTEMPERATURE TEST

7.1 Discussion of Results

The ASTM Standard Consumer Safety Specifications F444-78 and F445-78 set out requirements to ensure safety from scale and thermal shock respectively. The objectives are clearly highly desirable but the requirements to achieve these are not easily met when a solar system is part of the hot water supply system. The requirement of not allowing the outlet water temperature to exceed 49°C is not usually even met with conventional hot water tanks because they are typically set at about 60°C (but easily reset to lower temperatures). To be practical a 49°C tank setpoint would require a larger tank volume to maintain the same effective capacity but with this practice is essentially unheard of. It appears that a water temperature setpoint of 60°C, which may result in instant pain and scalding in 3 seconds, is commonly accepted as a practical compromise between convenience (capacity), cost and safety. While it is reasonable to expect that SDHW systems should not increase the risk associated with using hot water it is not reasonable to make these systems less attractive economically in order to reduce that risk below the level that seems to be routinely accepted. It follows that the requirements imposed by ASTM F444-78 and F445-78 and ANSI/ASSE Standards 1016-1979 and 1017-1979 are too stringent for the single-family SDHW system application. CAN3-B125-M85 does not state a maximum allowable outlet temperature but does specify an allowable variation in temperature about a starting mixed water temperature of approximately 40°C. Minor changes to this standard should make it suitable for the SDHW system application. Suggested modifications to the ATCV test would include setting a higher nominal mixed water temperature, possibly 55°C, and increasing the variation in the hot water supply temperature from

$63 \pm 15^{\circ}\text{C}$ to say $63 \pm 30^{\circ}\text{C}$. The 55°C setpoint temperature is close to the typical 60°C supply temperature but leaves some room for variation before the risk of scalding is encountered. The 33 to 93°C range of supply temperatures is representative of those that may be produced by SDHW systems. The allowable variation in the outlet temperature as given in Table 1 (Section 3) should be studied to see if there is room to loosen the allowable temperature variation requirement for primary valves (installed at the hot water source, rather than at the point of use) that are intended to provide safe outlet temperatures. It is possible that the current requirements are oriented to shower valves that have comfort as an important design/test objective. The currently used test flow rate of "4.5 l/min minimum" also deserves examination as it is probably on the low side for the showering load.

The only valve tested in this study that was also tested by CSA to the requirements of the B125 standard, and is listed on the CSA List of Certified Plumbing Products [10], is the MCC Powers Model 420. The Sparco Aquamix is not on the CSA list but because its performance in the ORF tests was similar, though not equal, to that of the MCC Powers valve and because it has some pressure compensating capability it may be certifiable as well. It is unlikely that the other valves tested would be certifiable under B125 because of the $\pm 20\%$ pressure variations that are applied to the cold and hot water supply lines in turn.

7.2 Review of the Routine Overtemperature Test

The sections of CSA F379.1-M1985 dealing with routine overtemperature protection (6.15, 7.3.1 and 8.6.2) have been significantly changed and improved by the CSA Technical Committee since this study was initiated.

The review of these parts of the standard will therefore be based on the current draft (Appendix B of the Minutes of the CSA Technical Committee on SDHW Systems - F379.1 meeting held Nov. 27, 1986) which has been included in this report as Appendix A.

The purpose of these parts of the standard is to ensure that "the system is adequately protected against damage during periods when no hot water is drawn and when storage temperatures tend to be high" and to ensure that "the user is protected against scalding under these conditions". With regard to health and safety especially, it is a very difficult task to arrive at a balance between the absolutely safe requirements, as set down in the ASTM Consumer Safety Specifications [9, 10], described and discussed earlier, and the practical reality of attempting to put cost-effective systems into the marketplace. In general the standard appears to address reliability/durability and health/safety issues reasonably well. However, some general and specific comments and concerns have come out of the review process. Two general issues are raised first:

- (1) It is important to avoid restriction of innovation by ensuring a willingness to revise the standard as new ideas and products appear. The Product Approval Committee may also make exceptions and interpretations in the application of the current standard where appropriate.
- (2) Consideration needs to be given to how CSA tested Thermostatic Compensating Valves or other tempering devices will perform after some period of use in SDHW systems.

The following more specific comments/concerns are based primarily on the information gathered in this study:

- (1) Use of the maximum allowable temperature to the user of 63°C instead of the originally incorporated 60°C reduces the exposure time that produces scalding from 3 seconds to about 1.5 seconds [12]. This relative loss of safety is considered to be unreasonable for a 3°C increase in the permissible delivery temperature.
- (2) Allowing the maximum storage temperature to be "equal to the CSA B125 maximum testing temperature for the thermostatic compensating valve" is reasonably conservative, at this time, as this temperature is $78 \pm 3^{\circ}\text{C}$ in CAN3-B125-M85 (6.10.2) for testing outlet water temperature control.
- (3) The phrase "and collector top header liquid temperature" may be deleted from 8.6.2.2 since the requirement to keep the heat transfer fluid within its design temperature was dropped from 6.15. The removal of this requirement from 6.15 is not understood unless it has been added to another part of the standard.
- (4) "CSA B125" should probably be referred to as CAN 3-B125.
- (5) The sensor measuring draw water temperature should have a time constant of less than 0.5 seconds.
- (6) "Scalding" in the title of Section 8.6.2 should be changed to "Scald Protection".

8. CONCLUSIONS

As a result of the work undertaken it has been concluded that:

- (1) CAN 3-B125-M85, ANSI/ASSE Standards Nos. 1016-1979 and ASTM Standard Consumer Safety Specifications F444-78 and F445-78 all have some relevance to tempering valve performance, but none is ideally suited to testing tempering valves for the SDHW system application. CAN 3-B125 would be reasonably well suited to this application if the valves were tested at higher inlet water temperatures and if consideration was given to the intermittent nature of the tempering requirement.
- (2) The best valve tested for scald protection, the MCC Power's Hydroguard 420, was too expensive to be routinely employed in single-family sized SDHW systems. The remainder of the valves tested did not display a strong relationship between cost and performance.
- (3) All valves tested produced dangerous delivery water temperatures under some conditions. High flow rate and high supply temperatures were generally the most difficult conditions for the tempering valves to handle safely. High tempering valve setpoint temperature increased the risk.
- (4) Tempering valves are best used in conjunction with other means of limiting the water temperature.
- (5) The auxiliary tank tested reduced the temperature of water entering it above the setpoint temperature.

- (6) Setpoints of 60°C or higher essentially eliminate any capacity a fully heated tank has for reducing the temperature of hotter incoming water to a temperature that will not cause scalding.
- (7) Tanks which have a significant volume of water that is not heated by the auxiliary energy source (such as electric tanks with only one element operational) tend to keep the outlet temperature lower for longer periods of time.
- (8) Tanks used as a means of reducing the temperature of water reaching the user cannot be counted on to do this during periods when large amounts of very hot water supplied by the solar storage tank have used up all the available "buffering" capacity.
- (9) A 6m length of copper pipe reduced the water temperature by 0.5 to 1.5°C, depending on flow rate.
- (10) It should be possible to accelerate the aging of tempering valves using a relatively simple procedure.
- (11) The Routine Overtemperature Protection sections of CSA F379.1-M1985 have recently been significantly changed and improved by the Technical Committee. Some details need improvement but the current approach is fundamentally sound. A willingness to change the standard as new products and ideas make this necessary, is essential.

9. RECOMMENDATIONS

Tempering valves should be installed with a check valve to control unwanted cross flow between the hot and cold inlet ports, as discussed by Newell [13].

The valves purchased for this study were tested in the "new" condition. Their performance after 5 or 10 years of operation is just as important as the new performance. It is recommended that the "aged" performance of tempering valves be investigated both by using an accelerated aging procedure on promising valves and then retesting them and by locating tempering valves that have been in use for sometime and comparing their performance with new units.

The effect of pressure fluctuations on tempering valves was not investigated in this work. It is however believed to have a significant impact on the outlet temperature of the lower cost tempering valves. The importance of this parameter should be investigated.

While tempering valves may allow the upper operating temperature limit for a system to be increased, thereby reducing dumped energy and increasing delivered energy, it is also true that tempering water for certain loads (that aren't manually tempered/mixed at the faucet) such as the dishwasher and clothes washer will reduce the volume of hot water drawn and therefore reduce the solar energy contribution to these loads. The magnitude of this effect should be estimated. The result would provide one input to an overall cost/benefit analysis in which the energy (and therefore cost) value of different upper operating temperature limits for SDHW systems would be estimated using a program such as WATSUN. This analysis may suggest that operation at the very high temperatures supplies little incremental energy and therefore controller limiting of high temperature operation may be attractive relative to high performance tempering hardware.

The tempering valves employed in this study were tested at two flow rates and three supply temperatures. The most promising valves should be retested at intermediate flow rates and temperatures to better define the limits of safe operation. It would also be instructive to learn if any of the under \$100 valves would pass CAN B-125 M85.

The availability of a shower control valve, that has passed ANSI/ASSE 1016-1979, at approximately \$100 was discovered during the preparation of this report. It should be investigated for possible primary application (installation on the hot water supply system).

Only one auxiliary tank was employed in the buffering tests. Other designs and sizes should be tested for possible inlet to outlet "streaming".

The performance of a small volume tank (on the order of 20 litres) as a means of eliminating short term high temperature spikes, that can come from a tempering valve, should also be investigated.

For thermosyphon and integral collector-storage systems, which are not shut down by a controller, the use of two tempering valves might provide an acceptable means of reducing the likelihood of high temperature water reaching the user. Two valves in series should result in lower delivery temperatures from the second valve. Two valves in parallel should also produce lower delivery temperatures at high flow rates. These configurations should be at high flow rates. These configurations should be tested with a promising tempering valve.

A tempering valve should be tested in conjunction with an auxiliary tank (ie. combine the two tests done in this study) to confirm the validity of the component tests performed in this study.

10. REFERENCES

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APPENDIX A

6.15 Routine Overtemperature Protection

Systems shall be tested for protection against damage or hazards caused by excessive heat transfer liquid temperatures that may arise during routine operation. Tests shall be in accordance with Clause 8.6.2.

A system shall pass this test if no visible damage has occurred.

7.3.1 Scalding

Domestic hot water systems shall be designed in such a way that the temperature of the hot water available to the user cannot exceed 63°C. Action taken by the system to prevent higher temperatures from occurring shall not interfere with the subsequent normal functioning of the system.

Systems shall be tested in accordance with Clause 8.6.2 and shall pass the test if the system delivery temperature does not exceed 63°C and the maximum allowable storage temperature is not exceeded. The maximum allowable storage temperature is equal to the CSA B125 maximum testing temperature for the thermostatic compensating valve employed or the maximum test temperature for some other tempering device employed that meets a CSA standard.

8.6.2 Routine Overtemperature/Scalding Test Procedure

8.6.2.1 Purpose

The purpose of this test is to determine whether the system is adequately protected against damage during periods when no hot water is drawn and when storage temperatures tend to be high (6.15); this test also determines whether the user is protected against scalding (7.3.1) under these conditions.

8.6.2.2 Apparatus

The apparatus shall comprise a means of supplying and measuring simulated solar energy (i.e. a simulator lamp or an electrical heater) and means to determine the solar storage tank temperature, draw water temperature and collector top header liquid temperature to within 1°C . This means to determine draw water temperature must be immersed in the hot water delivery line from the last tank supplied with the system and have a time constant ≤ 2 seconds.

8.6.2.3 Procedure

The system shall be assembled according to the manufacturer's instructions. The solar storage media shall be at 63°C and the auxiliary thermostat, if adjustable, on solar plus supplemental systems set at 60°C or according to manufacturer's instructions, whichever is higher. Simulated solar energy shall be added to the collector array at a rate equivalent to a total irradiance of 1000W/m^2 in the plane of the collector array with an ambient temperature of 30°C .

This energy shall be added continuously until:

- (a) 8 hours have elapsed or
- (b) the tank temperature has stabilized (the rate of rise of temperature falls below 1°C per hour) or
- (c) the maximum temperature has been exceeded or
- (d) collectors drain.

The storage tank temperature shall be noted and a volume of water equal to the volume of the system shall be drawn at a rate of 10 l/min $\pm 5\%$. The measured draw water temperature shall be recorded for draw increments of 5 l or less.

8.6.2.4 Reporting Requirement

The duration of the test and the conditions under which the test was terminated shall be reported.

The maximum temperatures measured for the solar storage tank and the water drawn shall be reported. Any visible damage that occurs to any component of the system and any occurrence that may affect subsequent system operation shall be reported.